Liu *et al.*
BMC Medical Informatics and Decision Making (2024) 24:400
https://doi.org/10.1186/s12911-024-02826-3

BMC Medical Informatics and Decision Making

RESEARCH

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Development and evaluation of a clinical nursing decision support system for the prevention of neonatal hypoglycaemia

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Abstract

Background Hypoglycaemia is one of the most common complications during the neonatal period. Recurrent hypoglycaemia episodes can result in neurodevelopmental deficits and even sudden death. Available evidence indicates that healthcare professionals ought to promptly assess the risk of hypoglycaemia in newborns immediately following birth and formulate the most suitable preventive strategies. Consequently, this study was designed to develop a clinical nursing decision support system for neonatal hypoglycaemia prevention based on the prediction model for neonatal hypoglycaemia risk that was developed in a previous study, and to evaluate its efficacy.

Methods Nursing process as the theoretical framework, based on evidence-based nursing, standardized nursing language, and clinical decision support technology, the neonatal hypoglycaemia prevention nursing decision support system was developed.This system was implemented in the neonatology department of a tertiary grade A general hospital from September 1st to 30th, 2023.The application efficacy of the system was assessed and compared through the examination of the incidence of neonatal hypoglycemia, adverse outcomes associated with neonatal hypoglycemia, and the experiences of nurses following the implementation of the system.

Results The incidence of neonatal hypoglycaemia decreased after the system was implemented, and the difference was statistically significant ($X^2 = 4.522$, $P = 0.033$). None of the neonates experienced adverse outcomes during hospitalization. The rate of hypoglycaemia risk assessment in neonates after system implementation was 92.16%. The total Clinical Nursing Information System Effectiveness Evaluation Scale score was 104.36 ± 1.96.

Conclusion The neonatal hypoglycaemia prevention nursing decision support system realizes neonatal hypoglycaemia risk assessment, intelligent decision-making, and effect evaluation, effectively diminishes the incidence of neonatal hypoglycaemia, and enhances the standardization of neonatal hypoglycaemia management.

Keywords Neonatal hypoglycaemia, Clinical nursing decision support system, Risk assessment, Knowledge base

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Background

Neonatal hypoglycaemia (NH) is a common clinical metabolic disease in newborns, and the diagnostic criteria and intervention thresholds are controversial [1, 2]. The 5th edition of Practical Neonatology in China defines the diagnostic criterion for NH as a blood glucose level less than 2.2 mmol/L and that for critical hypoglycaemia requiring clinical intervention as a blood glucose level less than 2.6 mmol/L [3]. The prevalence of NH ranges from 4 to 12% and reaches more than 30% in high-risk newborns [4, 5]. Transient and physiological hypoglycemia of newborns, low glucose level in the body, resulting in sweating, tremors and jitteriness, pallor, weakness, and poor feeding. The evidence of long-term effects of early, transient hypoglycaemia is still conflicting [6] but in a follow-up study of infants at risk of hypoglycaemia, infants who were exposed to hypoglycaemia had worse visual, motor and executive function at 4.5 years of age [7]. Furthermore, moderate hypoglycaemia could be associated with adverse neurocognitive outcome at 2–6 years of age [8]. Severe hypoglycaemia persisting for over 12 h exerts a more profound impact on the neonatal brain compared to ischaemia and hypoxia, and these neonates are predisposed to mental retardation, neurological impairments, and even sudden death [9]. The effective prevention of NH is considerably more significant than treatment, and early identification is crucial for achieving NH risk management.

However, Clinical symptoms may be unspecific, such as poor feeding, hypothermia, sweating, tremors and jitteriness [10, 11]. In addition, the occurrence of NH is associated with a multitude of factors, such as gestational age, birth weight, the presence of asphyxia, infections and comorbidities, including other medical or surgical disorders, maternal diabetes or gestational hypertension, and a maternal history of the use of medications such as beta-blockers or oral hypoglycemics, which increase the risk of NH [12, 13]. Australian scholars constructed an NH risk prediction model based on a gradient-enhanced tree machine learning method using a sample of hospitalized neonates with a gestational age < 39 weeks as the study subjects, and the findings indicated that gestational age, neonatal birth weight, gestational diabetes mellitus, and maternal body mass index were the four independent risk factors for NH [13]. Our research team performed a study with 2724 neonates and constructed a risk prediction model for NH using logistic regression, which revealed that preterm delivery, small for gestational age, hypothermia, poor feeding, maternal diabetes and maternal hypertension were the 6 independent risk factors for NH [14]. In 2011, the Committee on the Foetus and Newborn [15] proposed that preventive management should be individualized for newborns based on different risks. Nevertheless, the current risk screening approach for high-risk NH remains ambiguous, and there is a deficiency in systematic graded preventive management strategies. This leads to difficulties for nurses in promptly identifying high-risk newborns and formulating the most suitable preventive decisions.

The Clinical Nursing Decision Support System (CNDSS) is an evidence-based nursing intervention that can provide nurses with scientific decision-making guidance, this system was developed by employing the nursing process as the theoretical framework and is based on nursing research, predefined nursing diagnoses, correct determination of the linkages between diagnoses, and orientation to patient outcomes. Nursing decision-making involves professional decisions made by nursing staff within a variety of clinical environments; it is not only an important part of nursing practice but also reflects the professionalism of nurses and guarantees the promotion of patient health [16, 17]. Improving the efficiency of nursing staff and ensuring the safety of patients with the help of information technology has always been a hot topic in nursing research. Presently, the application of the CNDSS is mostly focused on acute and critical care, chronic care, and adult hypoglycaemia management, and there are no reports of its application in NH prevention management [18–20]. Consequently, this study was designed to develop a clinical nursing decision support system for neonatal hypoglycaemia prevention based on the prediction model for neonatal hypoglycaemia risk that was developed in a previous study, and to evaluate its efficacy.

Methods

Design

This study was conducted in 2 phases from 2022 to 2023. Phase 1 was the construction of the Clinical Nursing Decision Support System for NH Prevention,the B/S architecture, background C# language, data stored in the ORACLE database developed on desktop computers, PDA as a hardware platform, and wired, wireless LAN as a network platform were used to support the computer side and PDA side of the common operation; Phase 2 was the application of the Clinical Nursing Decision Support System,and the effectiveness of the system was evaluated using historical controls.

Phase 1

Constructing the NH prevention assessment module from January to March 2022

Our research team constructed an NH risk prediction model in a previous study [14]. In this study, a total of 19 risk factors were incorporated, which were determined based on relevant guidelines, best evidence summaries, as well as the opinions of clinical experts.The clinical information regarding neonatal risk factors encompassed aspects such as sex, gestational age, birth mass, birth temperature, APGAR score, feeding status, number of fetuses, mode of delivery, and the presence of comorbidities. These comorbidities included intrauterine distress, asphyxia or resuscitation, congenital heart disease, erythrocytosis, sepsis, among others. The clinical information related to maternal risk factors covered elements like age, maternal diabetes mellitus, maternal hypertension, and the use of medications during pregnancy, etc. Binary regression analysis showed that preterm, small for gestational age, hypothermia, poor feeding, maternal diabetes mellitus, and maternal hypertension were 6 independent risk factors for NH, and the model formula was as follows:

$$Z = 1.184 \times \text{preterm} + 0.948 \times \text{small for gestational age} + 0.837 \times \text{hypothermia} + 0.830 \times \text{poor feeding} + 1.075 \times \text{maternal diabetes} + 0.931 \times \text{maternal hypertension} - 3.719.$$

Nomograms of NH risk prediction is shown in Fig. 1. Based on the prediction model formula, the Hosmer–Lemeshow test was used to verify the fitting effect of the model using a calibration curve ($X^2=6.162$, $P=0.405$). The predictive effect of the model was tested using an ROC curve, with Youden index as the maximum critical value of the prediction model, i.e., the cut-off was 0.114, the area under the ROC curve was 0.814, the 95% *Cl* was 0.796 and 0.831, the Youden index was 0.491, the sensitivity was 0.769, and the specificity was 0.722. ROC curve of NH risk prediction model is shown in Fig. 2. The model predicted NH well, and according to the model prediction threshold (P = 0.114), the infants were categorized into low-risk and high-risk groups, which is the basis for nurses to implement hypoglycaemia graded preventive management measures for newborns. The NH risk prediction tool was implemented in the system, and the NH prevention assessment module was formed.

Constructing the NH Preventive Care Knowledge Base from April to December 2022

This section focuses on the construction of the knowledge base for NH preventive care using an evidence-based approach and the Delphi method. (i) After team discussion, the best evidence summarized in the NH prevention and management strategy published by Zhang et al. [21] in 2020 was used as the basis for a supplemental search of best practice information books, recommended practices, guidelines, evidence summaries, systematic evaluations, and expert consensuses that were updated and published after August 2019 to extract additional data. We searched the following databases using the keywords "Hypoglycaemia/Blood sugar" AND "Newborn/Infant" AND "Assessment/Prevention/Management" AND (OR) "Guideline/Clinical practice/Expert consensus" for all evidence on NH prevention and management: BMJ Best Practice, UpToDate Joanna

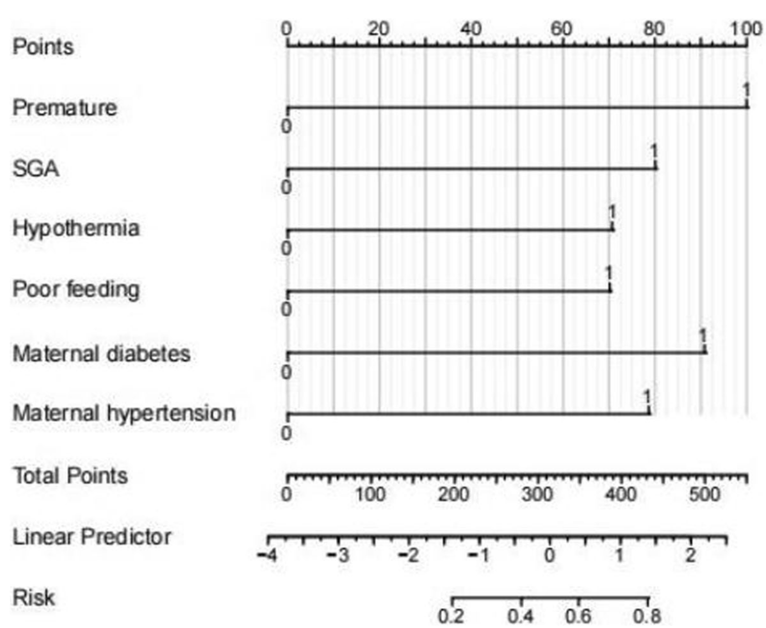

Fig. 1 Nomograms of NH risk prediction

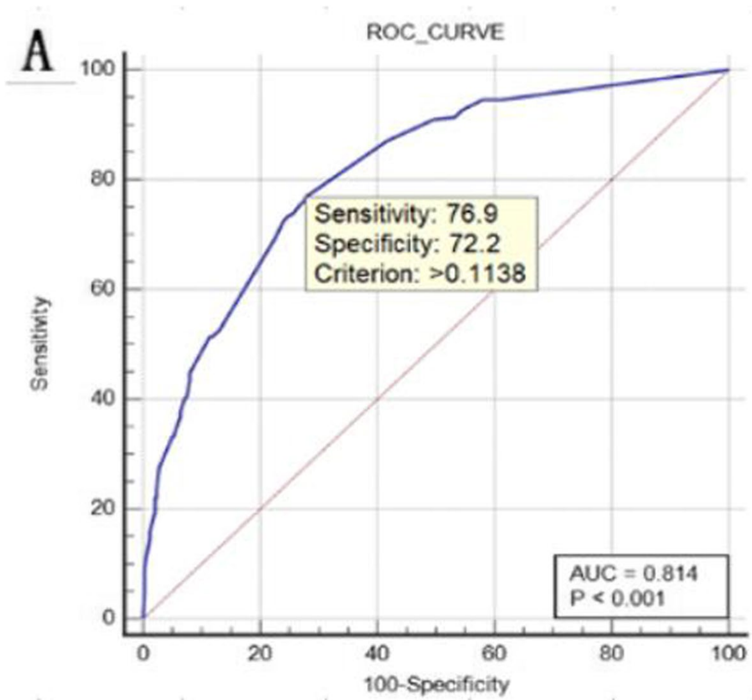

Fig. 2 ROC curve for predicting the occurrence of NH

Briggs Institute Centre for Evidence-Based Health Care, National Institute for Health and Clinical Excellence Guideline Network, Ontario Association of Registered Nurses, Cochrane Library, PubMed, Canadian Paediatric Society, et al. (ii) Two researchers extracted new evidence and summarized and merged it with the best evidence on NH prevention and management strategies published in 2020 to formulate the initial draft of the knowledge base. Six nursing experts possessing extensive practical and managerial experience in NH were invited to assess the wording, expression, comprehensiveness, practicality, and scientific validity of the content of the initial draft of the knowledge base. The draft was then revised in accordance with the experts' recommendations to generate the final draft. (iii) The final draft of the knowledge base was standardized and coded using the Clinical Care Classification (CCC) [22], and the core nursing interventions were coded using a 4-digit character code of "letters + numbers", with the first character being the initial letter of the nursing field, and the next 3 characters being the initial letters of the corresponding core nursing interventions. There were 4 types of nursing activity type modifiers, with the numbers 1, 2, 3, and 4 indicating that 2 or more nursing measures belonged to the same core nursing interventions and to the same type of activity according to the characters a, b, and c.

Constructing the NH care plan module from January to March 2023

The interface is designed to realize automatic triggering of nursing diagnosis, automatic recommendation of nursing measures, intelligent reminders of nursing outcome evaluations, and the automatic formation of structured nursing record sheets. The details are as follows: (i) Nursing diagnosis automatic triggering: In the nursing assessment interface, when the NH score is > 0.114, the system automatically jumps from the nursing assessment module to the nursing plan module and automatically triggers the nursing diagnosis. (ii) Nursing measures are automatically recommended: each NH preventive nursing measure in the knowledge base is entered into the system in a checkable way, and nurses do not need to edit it to ensure the formatting and standardization of the instrument. When the nursing diagnosis is triggered, the system automatically recommends the nursing measures that should be taken, and the nurse can check the boxes according to the risk factors related to the NH to formulate personalized nursing measures. (iii) Intelligent reminders for nursing outcome evaluations: When the

NH reassessment score is ≤ 0.114, the system calculates the termination time of the nursing diagnosis, reminds the nurse to carry out the nursing outcome evaluation, and simultaneously records the evaluation time at the same time. (iv) Structured nursing records include the nursing diagnosis and time, nursing measures, nursing outcomes and time, and nurses' signatures. The CNDSS Framework for neonatal hypoglycaemia is shown in Fig. 3.

Phase 2

Research participants

Newborns admitted to the neonatal department during the period from June to August 2023 (prior to the implementation of the system) and from October to December 2023 (subsequent to the system implementation) were selected as the study participants. The inclusion criteria for newborns were as follows: (i) Infants within 28 days after umbilical cord ligation [3]; and (ii) the legal guardians of the newborn infants provided informed consent and voluntarily enrolled in this study. The exclusion criteria were as follows: (i) hypoglycaemia caused by endocrine diseases such as pituitary hypoplasia and glucagon deficiency; (ii) hypoglycaemia caused by combined chromosomal abnormalities and genetic metabolic diseases; and (iii) hospitalization for less than 48 h or transfer to other wards during the study period. To evaluate the nurses' experience using the information system, neonatal nurses were also incorporated as study subjects. Ethical approval was obtained from the Affiliated Hospital of Jiangsu University (KY2022H0507-7).

Sample size

We calculated the sample size based on the primary outcome(Incidence of hypoglycaemia in neonates).Based on the incidence of hypoglycemia reported in previous literature, control group $\widehat{\pi}_1 = 12.31\%$, experimental group $\widehat{\pi}_1 = 1.54\%$, set α as 0.05, β as 0.10, and f(α,β) lookup table as 10.5.Subsequently, the required sample size for each group was calculated to be 115 cases. Taking into account a sample loss rate of 10%, it was concluded that more than 127 cases could be included in this study. The formula is as follows:

$$n = \frac{\widehat{\pi}_1(100-\widehat{\pi}_1)+\pi_2(100-\widehat{\pi}_2)}{(\widehat{\pi}_2-\widehat{\pi}_1)^2} f(\alpha,\beta)$$

Application methods

From September 1st to 30th, 2023, we facilitated the selection of our neonatal department to run the system. (i) Nurse training: The training was based on operational demonstrations, and a system operation guide was issued, which described in detail the process of the entire system and the operation methods and roles of each module. (ii) Members of the research and construction team went to the wards to collect data on the problems encountered during the operation of the system and the feedback of clinical nurses' experiences using the system to make program adjustments and improve the system's triggering rules and forms of

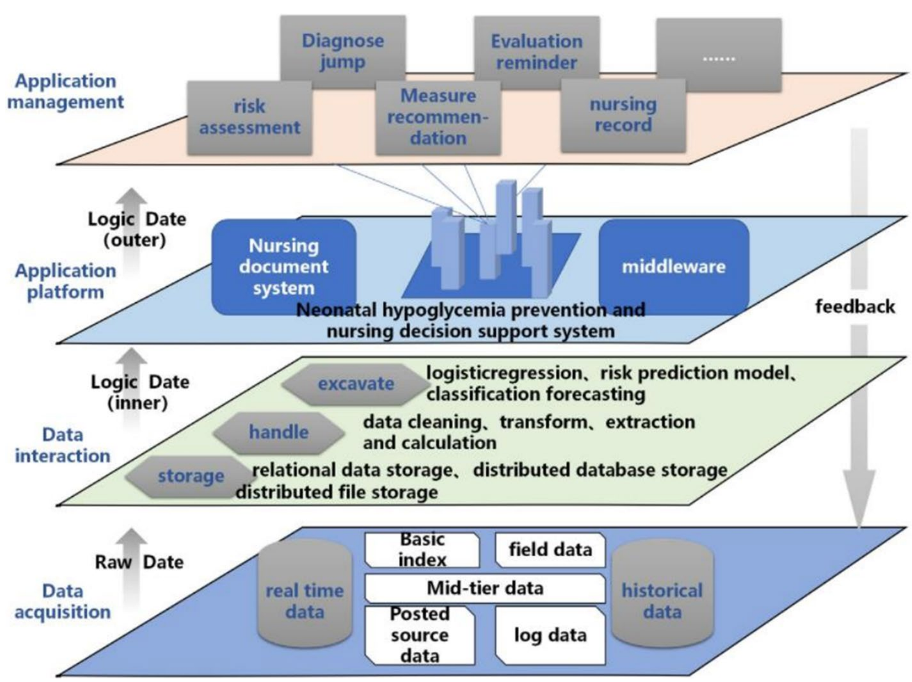

Fig. 3 The CNDSS Framework for NH

expression, including the process, language, colour, and layout. (iii) A system discussion group was established consisting of all clinical nurses in the wards, all members of the system research and construction team. During the operation of the system, in the event that clinical nurses come across problems such as system lags, information errors or data loss, they are required to provide prompt feedback within the group. System developers bear the responsibility of resolving these issues expeditiously and releasing instructions for upgrading the information system. Members from the Nursing Department, Information Department and Quality Control are primarily engaged in the task of supervision.

Evaluation indicators

(i) Incidence of hypoglycaemia in neonates: number of cases of hypoglycaemia (blood glucose level < 2.2 mmol/L) in neonates during hospitalization/total number of neonates × 100%.
(ii) Incidence of critical hypoglycaemia in neonates: number of cases of critical hypoglycaemia (blood glucose level < 2.6 mmol/L) in neonates during hospitalization/ total number of neonates × 100%.
(iii) hypoglycaemia-related adverse outcomes in neonates: number of cases of adverse outcomes such as respiratory irregularities, convulsions and tremors caused by hypoglycaemia in neonates during hospitalization.
(iv) Hypoglycaemia risk assessment rate of neonates: the number of neonates in which hypoglycaemia risk assessment was completed within 30 min after admission to the department/total number of neonatal cases × 100%.
(v) Nurses' experiences using the system was surveyed using the Clinical Nursing Information System Effectiveness Evaluation Scale. The scale was compiled by Zhao et al. [23] in 2020. It is composed of five dimensions, namely system quality, information quality, service quality, user satisfaction, and net benefit, encompassing a total of 23 items. Each item is rated on a 5-point Likert scale from 1 to 5, corresponding to "Strongly Disagree" to "Strongly Agree". The total content validity index of the scale was 0.975, the content validity index of each item ranged from 0.80–1.00, and the total Cronbach's α coefficient was 0.768.

Data collection

The investigators underwent uniform training, and consistent questionnaires as well as identical determination conditions were adopted throughout the data collection process. The results of the study were designated for preservation. Meanwhile, 5% to 10% of the patients were selected from this dataset for data re-examination, during which the data analysis was conducted by different personnel.

Data analysis

Data were analysed by SPSS 22.0. Quantitative data were described by the mean values and SDs. Qualitative data were described by frequencies and percentages. Quantitative data that conformed to a normal distribution and homogeneity of variance were analysed by one-way analysis of variance. A chi-square test was used to compare qualitative data. A two-sided test was used, and the test level was $\alpha = 0.05$.

Results

The CNDSS for neonatal hypoglycaemia assessment

When newborns were admitted to the department, the CNDSS reminded nurses to screen newborns for hypoglycaemia risk through window pop-ups and electronic alerts and to check the 6 risk factors on the scale, and the computer automatically calculated the NH risk value and pushed a high-risk warning. The CNDSS for neonatal hypoglycaemia assessment is shown in Fig. 4.

The NH preventive care knowledge base

Including 1 nursing diagnosis and 18 specific nursing interventions, as shown in Table 1.

Characteristics of neonates

A total of 188 neonates were enrolled before the implementation of the NH nursing decision support system (June

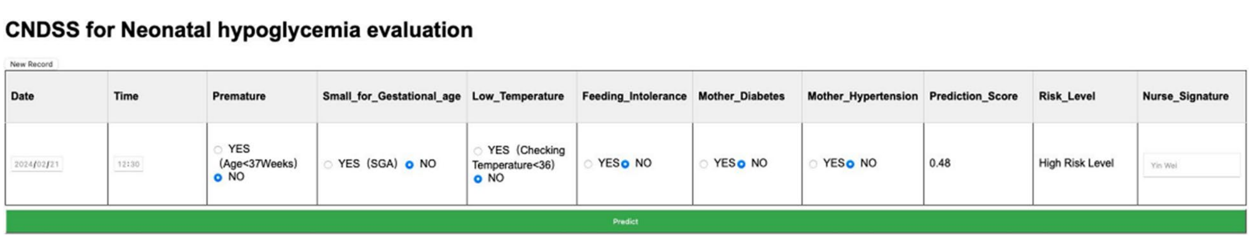

Fig. 4 NH risk assessment system

Table 1 NH preventive care knowledge base

Categorization	Items	Codes
nursing diagnosis	Endocrine changes: risk of hypoglycaemia	I22.0
Nursing care measures	1. Intervene when the neonate's blood glucose level is less than 2.6 mmol/L	I27.0.1a
	2. Risk stratification was determined by applying the neonatal hypoglycaemia risk prediction model within 30 min after birth, and P > 0.114 was considered to indicate that a neonate was at high risk of hypoglycaemia	I27.0.1b
	3. Maintaining stable external temperature: preheat the radiation table, warming box, clothing, wrapping, etc., maintain the room temperature at 24 ~ 26℃, and record the temperature and humidity every shift	K33.2.2a
	4. Measures to increase warmth: check whether the skin is clean and dry after entering the neonatal department, wear pre-warmed clothing in advance, and use a hat to reduce heat dissipation if necessary	K33.2.2b
	5. Hypothermic neonates: 1 h after rewarming, remeasure the temperature, adjust warming measures according to the body temperature in a timely manner, perform the incubator bird's nest type of care, use centralized nursing operations, nonessential not to go out to check; measure the body temperature every 30 min to determine whether it has returned to normal, after which adjusting checks to 1 time every 4 h.	K33.2.2c
	6. Improvement of equipment and access to out-of-home inspections	K33.2.2d
	7. If there is no contraindication to feeding, start feeding as early as possible (within 1 h of admission), with at least 7.5 ml/kg per feeding, including on-demand feeding, and a feeding frequency of at least 3 h/feeding or more frequently (nasal feeding should be used for preterm infants < 35 weeks)	J66.0.2a
	8. Breastfeeding is preferred, and formula milk can be added when breast milk is insufficient; face-to-face or telephone health education on the necessity of breastfeeding should be provided to mothers or parents of newborns, and they should be educated on breast milk collection, storage and transportation to improve the success rate of breastfeeding during hospitalization	J66.0.2b
	9. The crow's nest lying position is preferred in the incubator to promote the digestion of milk	J66.0.2c
	10.perform abdominal massage 10 min before feeding, 30 min before feeding, and 60 min after feeding to promote gastrointestinal motility	J66.0.2d
	11. Neonatal hypoglycaemia in high-risk infants to determine the effectiveness of the first feeding	I27.0.2a
	12. Children at high risk of hypoglycaemia should be screened for their first blood glucose level 30 min after the first effective feeding, and the screening should be completed within 2 h after birth. For infants with a normal blood glucose level, monitor the prefeeding blood glucose every 3 ~ 6 h for 24 h; otherwise, notify the physician and look for the cause of hypoglycaemia	I27.0.2b
	13. If the first feeding is ineffective and the infant is asymptomatic, closely monitor the blood glucose level, supplement with glucose solution if necessary, and retest the blood glucose level after 30 min; otherwise, follow medical advice to replenish fluids and continuously monitor blood glucose	I27.0.2c
	14. Observe for common symptoms of hypoglycaemia: shaking, cyanosis, pallor, crying, hypotonia, and poor feeding	I27.0.4a
	15. Pay close attention to feeding, temperature, muscle tone, respiration and colour	I27.0.4b
	16. Record the amount and time of feeding and the blood glucose level and measurement time and report and deal with any poor feeding and blood glucose abnormality in a timely manner	I27.0.4c
	17. Discharge is not recommended for children at high risk of hypoglycaemia for less than 24 h, poor feeding or unstable blood glucose levels	I27.0.3a
	18. Provide parents and caregivers of children at high risk for hypoglycaemia with an opportunity for information and discussion. Provide verbal and written information on the concepts and symptoms of neonatal hypoglycaemia, preventive care measures, the purpose of blood glucose monitoring, and related treatments	I27.0.3a

to August 2023), 101 (53.7%) of whom were males and 87 (46.3%) of whom were females. A total of 204 neonates were enrolled after the stable operation of the NH nursing decision support system (October to December 2023), 111 (54.4%) of whom were males and 93 (45.6%) of whom were females. The general information of the neonates in the two groups before and after the operation of the NH nursing decision support system was compared, and the difference was not statistically significant (Table 2).

Characteristics of nurses

A total of 22 clinical nurses who were female, median age was 36 years (IQR: 30,54). All nurses had completed university qualifications, worked full-time in the neonatal department.

Incidence of hypoglycaemia and critical hypoglycaemia in neonates

The incidence of hypoglycaemia was 13.30% (25/188) before the NH nursing decision support system was implemented, the incidence of hypoglycaemia was 6.9% (14/204) after the system was stably implemented, and the difference between the two groups was statistically significant ($X^2 = 4.522$, $P = 0.033$). The incidence of critical hypoglycaemia before the NH nursing decision support system was implemented was 6.38% (12/188), the

Table 2 characteristics before and after system operation

		Before system operation (*n* = 188)	After system operation (*n* = 204)	X^2 /t	p
Gender	Male	101 (53.72)	111 (54.41)	0.019	0.891
	Female	87 (46.28)	93 (45.59)		
Birth weight	Low weight	45 (23.94)	36 (17.65)	2.516	0.282
	Normal weight	139 (73.94)	162 (79.41)		
	Macrosomia	4 (2.12)	6 (2.94)		
Gestational age	Preterm neonate	68 (36.17)	65 (31.86)	0.810	0.368
	Term neonate	120 (63.83)	139 (68.14)		
Mode of delivery	Caesarean section	119 (63.30)	138 (67.65)	0.820	0.365
	Born normally	69 (36.70)	66 (32.35)		
temperature	Hypothermia	1 (0.53)	3 (1.47)	0.854	0.624
	Normal temperature	187 (99.47)	201 (98.53)		
Feeding Methods	Exclusive breast milk	16 (8.51)	14 (6.86)	0.491	0.921
	Formula	45 (23.94)	48 (23.53)		
	Breast milk and formula	73 (38.83)	84 (41.18)		
	Intravenous nutrition	54 (28.72)	58 (28.43)		
Age of mother		30.47 ± 4.26	30.46 ± 17.82	-0.048	0.962
Maternal Diabetes Mellitus	Yes	47 (25)	46 (22.55)	0.325	0.569
	No	141 (75)	158 (77.45)		
Maternal gestational hypertension	Yes	23 (12.23)	17 (8.33)	1.625	0.202
	No	165 (87.77)	187 (91.67)		
Mother's medication history with beta-blockers or oral hypoglycemic agents	Yes	46 (24.47)	35 (17.16)	3.190	0.074
	No	142 (75.53)	169 (82.84)		

Table 3 The incidence of hypoglycemia and critical hypoglycemia in neonates

	Before system operation	After system operation	X^2	P
Hypoglycemia [times, (%)]	25 (13.30%)	14 (6.9%)	4.522	0.033
Critical hypoglycemia [times, (%)]	12 (6.38%)	9 (4.41%)	0.750	0.387

incidence of critical hypoglycaemia after stable implementation of the system was 4.41% (9/204), and the difference between the two groups was not statistically significant ($X^2 = 0.750$, $P = 0.387$). There were no adverse outcomes in neonates during hospitalization before the implementation of the system or after the stable implementation of the system (Table 3).

Neonatal hypoglycaemia risk assessment rate

The rate of neonatal hypoglycaemia assessment after system implementation was 92.16% (188/204).

Nurses' experiences with the NH decision support system

A total of 22 questionnaires were collected, and the total score of the Clinical Nursing Information System Effectiveness Evaluation Scale was 104.36 ± 1.96, with scores of 4.94 ± 0.11 for the system quality dimension, 4.60 ± 0.15 for the information quality dimension, 4.60 ± 0.27 for the service quality dimension, 4.06 ± 0.16 for the user satisfaction dimension, and 4.57 ± 0.15 for the net benefit dimension.

Discussion

Our study implanted a NH risk prediction model into the system, which is capable of facilitating nurses in promptly identifying neonates with a high risk of hypoglycemia. Using the NH risk prediction model as a grading tool and CCC as the standardized language, an evidence-based and expert revision method was applied to construct an NH graded preventive nursing knowledge base, which can achieve NH risk management, and this information is the basis for assisting nursing personnel in making clinical decisions. Computer decision support technology was integrated to form an NH preventive nursing decision support system, which provides scientific decision support for healthcare professionals through reminder, decision-making, warning, and data storage functions; reduces the incidence of NH; promotes the standardization of NH management; and realizes the risk management of NH.

Assessing the risk of a disease is one of the greatest challenges in medical sciences. Most clinical decisions are made based on physicians' personal understanding and experience; however, their expertise may not be adequate for assessing the risk of all diseases or disorders. Therefore, the risk assessment of diseases has been the focus of many research studies in recent years [24]. Ahmadi et al. [25] used an artificial neural network to construct a clinical decision support system for predicting quality of life among elderly people, and the results showed that the clinical decision support system, which was designed based on the CFBP, is an efficient tool for increasing the quality of life among the elderly. Another study conducted by Chekin et al. [26] constructed a clinical decision support system for assessing the risk of cervical cancer, and the study confirmed that the system can facilitate the process of identifying people who are at risk of developing cervical cancer. In addition, the system can help to increase the quality of health care and reduce the costs associated with the treatment of cervical cancer. Current decision support systems for hypoglycaemia risk assessment are mostly focused on adults and those with gestational diabetes. Spat et al. [20] developed an interactive clinical decision support system for assessing the hypoglycaemic response in type 2 diabetic patients. Patients used the clinical decision support system to calculate the insulin dosage to avoid manual insulin dose calculation errors. Health care professionals can use the system to determine a patient's risk of hypoglycaemia due to the use of glucose-lowering medications resulting in the risk of hypoglycaemic reactions. In 2018, Abejirinde et al. [27] developed a clinical decision support system for risk identification, including GDM risk, to perform early prediction of women at risk for GDM, use colour signals to visualize cues for risk categories with urgency of referral, and push recommendations for counselling and treatment decision-making to health care providers. In our research, a pre-completed NH risk prediction model was adopted to facilitate healthcare providers in categorizing neonates who did not present with hypoglycaemia into different hypoglycaemic risk classes. This approach enabled the prompt identification of neonates at a high risk of NH, thereby allowing for the implementation of early preventive care measures. As a result, the incidence of neonatal hypoglycaemia was decreased.

As early as 2011, the Fetal and Neonatal Committee proposed that targeted preventive management strategies should be formulated for newborns based on different risk groups [15]. Nevertheless, both within the domestic context and on the international stage, the diagnostic criteria as well as the intervention thresholds for NH have remained controversial [1, 2]. According to the American Academy of Pediatrics (AAP) [15], NH can be diagnosed in neonates with blood glucose levels < 2.5 mmol/L in the first 24 h after birth and < 2.8 mmol/L in neonates 24 h after birth. Queensland Health (QLD) [12] recommends that a glucose level < 2.6 mmol/L should be considered NH, and a glucose level < 1.5 mmol/L should be considered to indicate severe hypoglycaemia. The Canadian Paediatric Society (CPS) suggests that a blood glucose level < 2.6 mmol/L for exclusively breastfed, appropriate-for-gestational-age term infants and a blood glucose level < 3.3 mmol/L for high-risk term, preterm, and small for gestational age newborns can be considered to indicate NH [28]. The 5th edition of Practical Neonatology in China defines that the criterion for determining hypoglycaemia is a blood glucose level of < 2.2 mmol/L.

The American Academy of Breastfeeding Medicine (ABM) suggests that a blood glucose level < 2.2 mmol/L in full-term healthy newborns and < 2.5 mmol/L in newborns with risk factors or clinical signs of hypoglycaemia are the thresholds for intervention [29]. According to the Paediatric Endocrine Society (PES), neonates with blood glucose levels < 2.8 mmol/L within 48 h of birth are at risk of hypoglycaemic brain injury, and therefore, it is recommended that blood glucose levels < 2.8 mmol/L be the threshold for intervention [30]. Dixon et al. [31] showed that 88% of 135 UK national health care departments used a blood glucose level < 2.6 mmol/L as the threshold for clinical intervention. A previous cross-sectional survey conducted by our research team revealed that the range of NH intervention thresholds in 21 hospitals in 13 cities ranged from 2.2 to 2.9 mmol/L, that the thresholds for hypoglycaemia intervention differed among different hospitals and even between neonatal and obstetrics departments in the same hospital, and that the lack of a uniform management specification for NH prevention in clinical practice caused a corresponding difference between the nursing staff in the prevention and management of NH [32].

The CNDSS is an overarching framework for the nursing process, based on nursing research, with predefined nursing diagnoses, correctly determined links between them, and patient outcome-oriented evidence-based nursing interventions that provide nurses with decision-making guidance. A typical CNDSS contains 3 parts: a reasoning machine, a knowledge base, and a human–machine interface, of which the knowledge base is the key of the whole system [33]. The knowledge base constructed in this study was based on the best evidence and used to develop the first draft of the NH-graded preventive care knowledge base, which guarantees the scientific validity of the knowledge base. In the Delphi method session, experts in the field of neonatal care were invited to evaluate the wording, expression, completeness, and usefulness of the content of the first draft of the knowledge base. When a newborn is admitted to the department, a pop-up window reminds the nurse to conduct an assessment, and the nurse only needs to check the yes or no box for the 6 risk factors. The system can automatically calculate whether the newborn is at high risk for hypoglycaemia. In the case of a high-risk baby, the system automatically jumps to the care plan module, where nurses can select personalized measures according to the newborn's high-risk factors, providing decision-making support and helping to promote the standardization of NH management.

Nurses' acceptance or satisfaction with the CNDSS is a key factor in applying the system [34]. Nurses can obtain patient information faster and make reasonable analyses and scientific judgment with the assistance of the CNDSS, thus reducing nursing errors and improving the quality and efficiency of clinical care. However, in the process of actual clinical application, the design of system functions, the quality of the knowledge base, and the usability, speed and flexibility of the system affects the use and promotion of the CNDSS [35–37]. For example, if the CNDSS only assesses the current risk factors for a patient and does not further provide appropriate nursing care for the risk factors, nurses will believe that this system only identifies the current problems of the patient without proposing effective solutions, which will lead to their unwillingness to continue to use the system. In this study, nurses' satisfaction with the NH preventive care decision support system, which was nurse-led, involved participation throughout the process, and comprehensively promoted, was high, and the trial was conducted before the opinions and suggestions of clinical users were solicited. Nurses can efficiently complete risk screening for NH after neonatal admission, provide personalized preventive care measures according to different risk levels, and form structured nursing records, which reduces the clinical nursing workload. The NH assessment rate in our study was more than 90%, indicating that nurses have a certain degree of acceptance, recognition, and adherence to the NH preventive nursing decision support system.

Research limitations

There are some limitations of this study. First, the NH risk prediction model applied in this study was a single-center study. A total of 2724 newborns from October 2015 to September 2020 were selected from Affiliated Hospital of Jiangsu University, and was divided into the modeling group and the verification group according to the ratio of 7:3.The model has not been externally validated and thus fails to fully represent the clinical characteristics of newborns in other regions or hospitals. Second, there are various parameters to assess the risk of NH; however, it is difficult to gather and consider all of these parameters in a single CNDSS. In this study, 6 independent risk factors were considered for developing the system based on the Binary regression analysis. Including other parameters in future systems and using more sophisticated methods for system design may help assess the risk of NH more precisely. Third, due to the time limitations, this study was unable to continuously gather outcome data at multiple time points before and after the implementation of the intervention.Finally,during the data collection phase, the researcher eliminated the data with missing values, and the final data had no relevant missing values.

Conclusion

In our study, based on the previously developed NH risk prediction model, we constructed an NH nursing decision support system with the following functions: automatic triggering of nursing diagnosis, automatic recommendation of nursing measures, intelligent reminders of nursing outcome evaluation, and automatic formation of structured nursing record sheets. This system effectively reduces the incidence of NH, realizes predictive risk management of NH, and can promote the standardization of NH management.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12911-024-02826-3.

Supplementary Material 1

Acknowledgements
All the authors of this manuscript have made substantial contributions to this work.

Authors' contributions
Songmei Cao designed the study, revised the manuscript. Qiaoyan Liu participated in the coordination of the whole work, analyzed data and writing manuscript. Jie Yang was responsible for the realization and optimization of the system functions. Lulu Sun and Wei Yin collected data,provided feedback on the nurses' experiences of using the system and performed checking and quality control. All authors read and approved the final manuscript for publication.

Funding
This work was supported by Chinese Nursing Association Foundation Program (ZHKY202113).The funding body played no role in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

Data availability
The data sets generated during and/or analyzed during this study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained from the Affiliated Hospital of Jiangsu University (KY2022H0507-7). Informed consent was obtained from all subjects and/or their legal guardian(s).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 23 March 2024 Accepted: 16 December 2024
Published online: 23 December 2024

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