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RESEARCH ARTICLE

Designing a Decision Support System to Diagnose Neonatal Clinical PICC Infection Using Fuzzy Logic

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ABSTRACT

Introduction: Peripherally inserted central catheters (PICC) have entered neonatal intensive care units (NICU) as an instrument to reach blood vessels [1]. Compared with central and peripheral venous catheters, PICCs have considerably reduced the side effects and complications [2-4]. The same instruments can be the cause of catheter-related bloodstream infection (CRBSI)[5]. The purpose of this study is to create a fuzzy expert system for the early diagnosis of catheter infection in newborns. **Materials and Methods:** Factors effective in infection diagnosis were determined by a questionnaire and based on pediatric subspecialists' comments. The system was designed bilingually (Persian and English) using C# software and SQL Server database. The output of the system is the percentage of infection risk. The system was assessed by the data of newborns' files in one of the hospitals in Tehran. **Results:** Following the assessment, the sensitivity of the system turned out to be 95% and its Specificity and accuracy were 88 and 91 percent, respectively. **Conclusion:** Non-specificity of clinical signs and laboratory findings of newborns' blood infection made its diagnosis difficult and uncertain. Using the designed expert system can be effective in the diagnosis of catheter-related blood infection.

Keywords: clinical decision support system, fuzzy logic, peripherally inserted central catheter (PICC), catheter-related blood infection

INTRODUCTION

Increase in premature birth has led to an increase in the need for NICU facilities such as vascular access devices[6]. Because of durability and prolonged use, PICC prevents a newborn to be needled repeatedly for peripheral vessels[3, 7]. This type of catheter makes possible the safe injection of materials such as hyperosmolar drugs or solutions containing non-physiological pH or stimulant or vesicatory materials, strengthening and nourishing solutions, water, electrolytes and antibiotics[1, 3, 8]. It is also a common, useful method for measuring the intravascular pressure[9]. PICC application has a lot of positive points such as the ease, low cost and safety of putting it into the body [2, 10, 11]. The incidence of catheter-related bloodstream infections in people with PICC -- compared with that of other intravenous catheters -- is less[12]. Although the use of PICC is often favorable in premature newborns, it is associated with the dangers of its complications such as thrombosis and also infectious problems, particularly systemic sepsis [8, 13]. Catheter-related bloodstream infections (CRBSIs) in peripherally inserted central catheters (PICCs) in NICU have been reported about 13 in 1000 days of catheter use[14]. This type of infections has short- and long-term negative effects on newborns' survival and neurological development[15]. Despite many advances in blood

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infection treatment, its diagnosis is still among major problems. Clinical symptoms and laboratory findings of neonatal blood infection are often non-specific, and other non-infectious diseases in newborns such as aspiration syndrome and digestive track blockages can also create these clinical symptoms and laboratory findings[16]. The lack of specific diagnostic tests is among the important reasons for uncertainty in the diagnosis of sepsis[17]. Determination of important indicators is important for the early diagnosis of the disease. Therefore, the use of fuzzy instruments will be very helpful for the diagnosis of sepsis[18]. Fuzzy sets and fuzzy logic theory is a quite appropriate and applicable basis for the expansion of knowledge-based systems in medicine. These systems have application in the interpretation of medical findings and diagnosis of diseases[19]. In a study by Mani, et al (2014), a decision support system was designed for the early detection of late-onset neonatal sepsis, using machine learning technique. This system is dependent on the primary statistical society for recognition presentation[20]. Koller, et al (2015) designed a fuzzy system for the detection of nosocomial infections in newborns and adults [21]. Efosa, et al (2013) designed a fuzzy inference system for the diagnosis of neonatal sepsis. In this study, data mining technique has been used to represent data[18]. Reis, et al (2004), designed a fuzzy expert system for the diagnosis of neonatal resuscitation. The sensitivity of the system was computed to be 76.5% and its specificity was 94.8[22]. Fuzzy theories are quite appropriate for the description of vague and uncertain concepts in medicine such as fever (high or low) and weight (high or low), and are among the strong instruments to interact with vague concept[23]. Therefore, in the present study, fuzzy expert system is presented for the early detection of PICC-related bloodstream infection.

MATERIALS AND METHODS

Determination of diagnostic parameters: Effective diagnostic parameters in the expert system were collected by the use of articles and reliable sources, and consultation with specialists. These parameters were assessed by a questionnaire based on neonatologists' comments. The data were analyzed by excel software. Sixteen variables were selected from among 30 ones. Based on the results of the questionnaire, the selected parameters were prioritized with scoring. The selected diagnostic parameters and the impact percentage of each parameter are shown in Table 1 & Table 2.

Table-1: Primary Parameters

Demographic Variables	**Degree of Impact**										
	Without any effect	1	2	3	4	5	6	7	8	9	10
Newborn's Weight											
Number of Weeks of Pregnancy											
Newborn's Sex											
Blood Type											
Single or Multiple Birth											
Basic Problems in the Mother and Newborn	Degree of Impact										
	Without any effect	1	2	3	4	5	6	7	8	9	10
Apgar Score											
Early Onset Sepsis											
History of Any Type of Respiratory Problems											
History of Antibiotic Therapy in the Newborn											
History of Medication through the Catheter											
Anomaly											
History of Convulsion in the Newborn											
Pregnancy and Childbirth Problems: Pregnancy Infection, Premature Rupture of Membranes, Emergency Cesarean, Chorioamnionitis and Other Problems											
Diabetes, Convulsion, Blood Pressure, Abortion History and Other Problems in the Mother											
Inflammatory Symptoms Due to Catheter	Degree of Impact										
	Without any effect	1	2	3	4	5	6	7	8	9	10
Presence of Thrombophlebitis, Secretion or Inflammation at Catheter											
Clinical Signs of Infection after Catheterization (Weakness, Convulsion, Lethargy, Poor Feeding, Bulging Fontanelle											
Cardio-Respiratory Problems after the Catheterization											
Reduction of Newborn's Reflexes after Catheterization											
Hypotension after the Catheterization											
Hypothermia or Hyperthermia after Catheterization											
Skin Symptoms											
Catheter Not Functioning											

Emergency Catheterization											
Presence of Intravenous Catheter in body											
Inflammatory Laboratory Signs	Degree of Impact										
	Without any effect	1	2	3	4	5	6	7	8	9	10
Leukopenia or Leukocytosis after Catheterization											
Neutrophilia or Neutropenia after Catheterization											
Thrombocytopenia after Catheterization											
Hypoglycemia											
ABG Changes											
C-Reactive Protein (CRP)											
Anemia											
Blood Culture											
Urine Culture											

Table-2: Physicians' Selected Parameters

Row	Diagnostic Criterion	Range of Each Criterion	Values of Each Range	Weight Effect of Each Parameter in Infection Recognition	Percentage of Each Parameter's Effect in Infection Recognition
1	Birth Weight	Very Low	<1500 gr	1	2.94%
		Low	1500-2500 gr		
		Normal	>2500 gr		
2	Gestational Age	Pre-term	<37 weeks	1	2.94%
		Term	37-42 weeks		
		Post-term	>42 weeks		
3	Presence of Intravenous Catheter in body	<7 Days		1	2.94%
		8-14 Days		2	5.88%
		15-21 Days		3	8.83%
		22-28 Days		4	11.76%
		>29 Days		5	14.70%
4	History of Medication through a Catheter	Has		1	2.94%
		Doesn't Have			
5	Hypotension after the Catheterization	Has		3	8.83%
		Doesn't Have			
6	Hypothermia and Hyperthermia after the Catheterization	Body Temperature Decrease	<35.5 °C	3	8.83%
		Normal Temperature	35.5-37 °C		
		Body Temperature Increase	>37.5 °C		
7	Cardio-respiratory Problems after the Catheterization	Has		2	5.88%
		Doesn't Have			
8	Thrombo-cytopenia after the Catheterization	Decrease in Platelet	<150000 µL	2	5.88%
		Normal Platelet Counts	>150000 µL		
9	Neutrophilia or Neutropenia after the Catheterization	Neutropenia	<50%	2	5.88%
		Normal Neutrophilia	50%-60%		
		Neutrophilia	>60%		
10	Leukopenia or Leukocytosis after the Catheterization	Leukopenia	<4000 µL	2	5.88%
		Normal WBC	4000-12000 µL		
		Leukocytosis	>12000 µL		
11	Increased C-Reactive Protein (CRP) after the Catheterization	High	>10		5.88%
		Normal	<102		
12	Inflammatory Symptoms Due to the Site of Catheterization	Has		3	8.83%
		Doesn't Have			
13	Ultrasound or Radiographic Evidence Indicating the Presence of Thrombus in the Catheter	Has		3	8.83%
		Doesn't Have			
14	Emergency Catheterization	Has		2	5.88%

		Doesn't Have			
15	Pregnancy and Childbirth Complications	Has		1	2.94%
		Doesn't Have			
16	Presence of Basis-Problems in Newborns	Has		1	2.94%
		Doesn't Have			

Creation of fuzzy expert system: The basic structure of fuzzy system is composed of three conceptual parts. The first part includes the database of rules, which keeps the fuzzy rules presented for the system. The second part consists of the database that keeps in itself the membership functions used in fuzzy rules. And finally, part three is the inference mechanism and tries to reach a reasonable output, using the rules of membership functions and the existing realities [24, 25]. In this research study, system rules were designed based on entry criteria and the impact of each of these criteria. For fuzzy inference, Mamdani method is used. With the arrival of diagnostic criteria, fuzzy-building process takes place; then, the membership degree of each variable is determined and entered into the knowledge base of the system. Calculations are done on the inputs, and the final result is displayed in the output of the system as the percentage of infection risk. Fuzzy expert system was developed in bilingual (English and Persian) form by C# software and SQL Server database. This system can be installed and set up on any computer easily and without the need for voluminous software installation. Data entry is done in two ways by the user: entering the parameters' number by the user and determining the yes/no mode that is designed as default mode. If wrong values are entered for variables, the system can give a message to the user for correction.

Assessment of the system

The system was assessed by the medical records data of neonates that had been hospitalized and treated with PICCs in newborns' intensive care unit at Children's Medical Center from March 2013 to September 22, 2015. Using the collected data, the accuracy, precision, and sensitivity of the system were examined. All Identifying information of patients was unknown to the researchers and has been kept confidential. The Ethics Committee of Tehran University of Medical Sciences approved the study. Approval Number is S/280/5333 in 27/01/2016.

RESULTS

After determining the diagnostic parameters, considering the diagnostic priority of each parameter, all the modes for each input parameter were combined and the intended rules were defined for the knowledge base under the supervision of pediatric subspecialists. The knowledge base has if-then rules and after the rules are determined, the combination of membership degrees is assessed to determine the degree of output intensity. Getting the input data from the user, the expert system provides a percentage between zero and one hundred as the risk of catheter-related infection in a newborn having a PICC. The assessment of the system was done by the data recorded in newborns' records. The sensitivity of the system turned out to be 95% and its specificity and accuracy were 88 and 91 percent, respectively. Kappa statistics were calculated to evaluate agreement between the response of the system and the experts' diagnosis recorded in files (0.82, $P<0.0005$). The results indicated a highly acceptable agreement according to Landis-Koch criteria(26).

DISCUSSION

By protecting the health of a newborn's very sensitive skin, peripherally inserted central catheters (PICCs) are appropriate alternatives for all types of Intravenous (IV) Cannulas and central catheters [8]. The major complication of catheter is infection [3, 9]. Prevention of nosocomial infections including catheter-related blood infections has always attracted all doctors' attention and emphasis, and is a quite important part in newborns' care [10]. Expert systems have contributed to faster and better detection of neonatal sepsis so that they can recognize the likelihood of catching it prior to the serious spread of infection in body [20]. The fuzzy system designed by Koller, et al (2015) to diagnose nosocomial infection in newborns and adults is considered as an achievement in the early diagnosis of nosocomial infection [21]. In their study, four diagnostic parameters were entered; in our study, however, more complete and specialized variables were used and this is among the strong points of the present study. The assessment of diagnostic fuzzy system of neonatal sepsis designed by Efosa, et al (2013) was done

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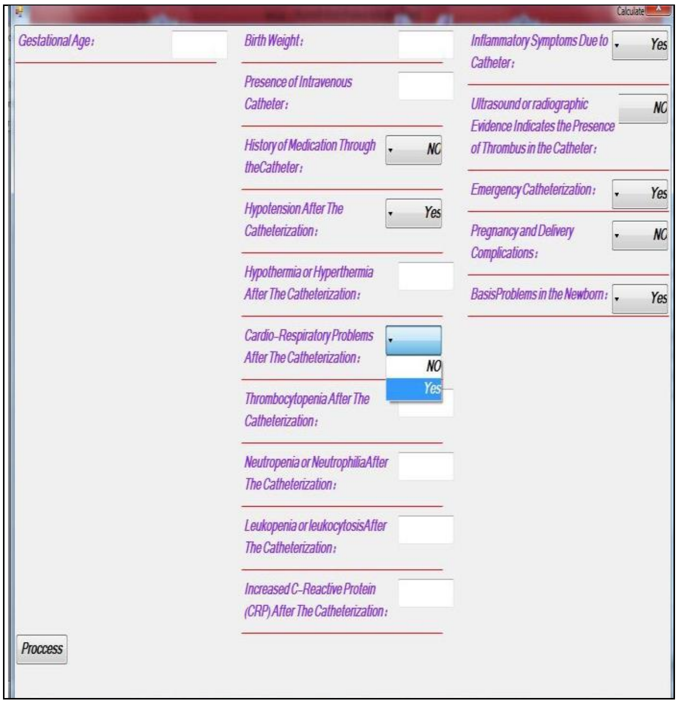
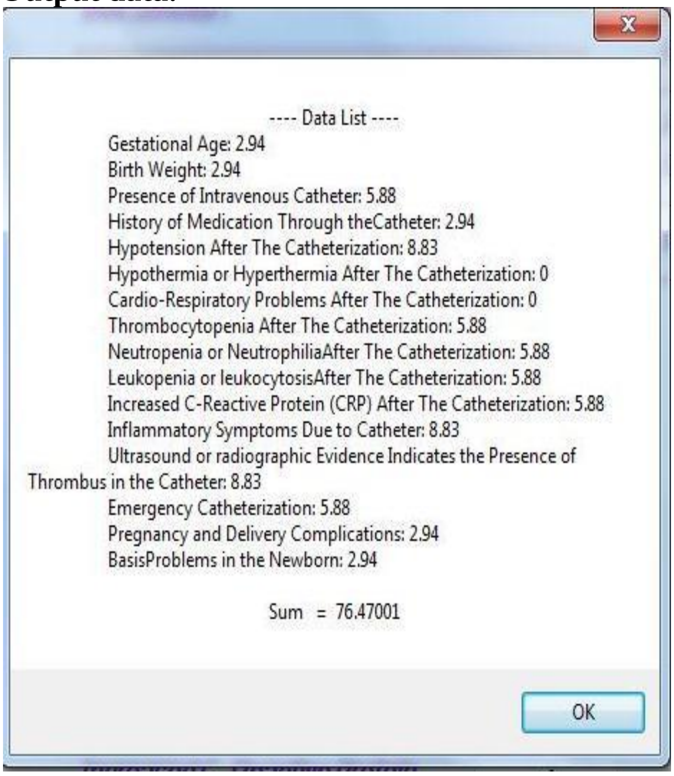
with 10 hypothetical diagnostic scenarios, and the system has offered a correct response to 8 of them [8]. In our study, the assessment of the system was performed in a real environment. The sensitivity, specificity, and accuracy of the system were done with the data contained in the records of newborns admitted to NICU. By computing Kappa coefficient, the compliance between the system output and doctors' diagnoses registered in files were compared.

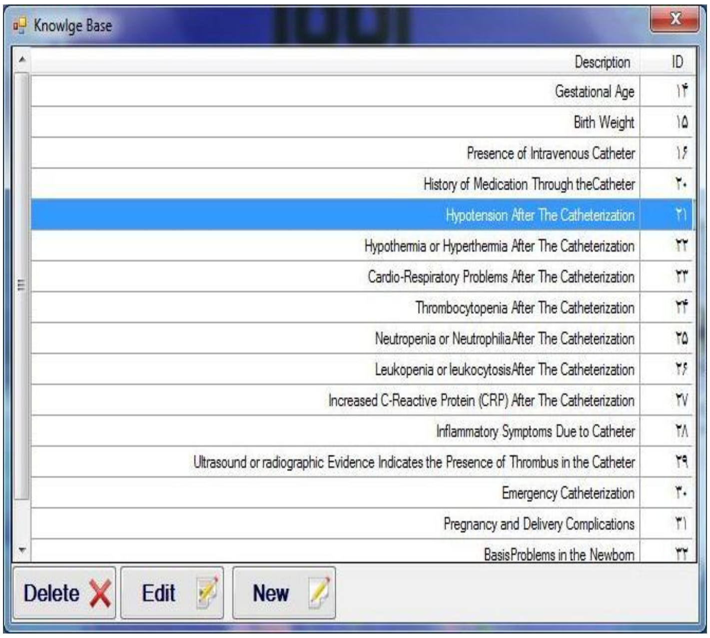
System interface: input data



Output data:



Knowledge base of system:



CONCLUSION

Fuzzy expert decision support systems model expert individuals' experiences, and in addition to working with uncertainty, they also decide in ambiguous conditions [27]. The results of research studies are about the ability of expert systems in diagnosis and prediction of newborns' diseases, which can improve the quality of newborns' health and play a role in the reduction of medical errors [28].

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