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Fuzzy Rule-Base Expert System for Evaluation Possibility of Fatal Asthma

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Abstract. Asthma, a chronic lung disease, has increasing rate in developing countries. Fatal asthma as a sudden exacerbation of asthma threatens the life of asthmatic patients, even patients with a condition of good-controlled asthma. So prediction the risk of fatal asthma is a great contribution decreasing the possibility of asthma mortality and morbidity. In this paper a fuzzy expert system is developed for prediction of fatal asthma. Fuzzy-rules, modular representation of variables in regard to patients' perception of the disease, and minimizing the need for laboratory data are the most important features of this system. Main variables of viral infection, Exposure to irritants/allergens, Duration of asthma, Response to treatment, Instability of asthma, Degree of nocturnal symptoms, Intensity of current treatment, Peripheral blood eosinophilia, and Intensity of exacerbation make antecedents of the rules. Output of this system is possibility of fatal asthma determined in the interval (0-10). Evaluating the performance of this system at asthma, allergy, immunology research center of Emam Khomeini hospital reinforces the good efficiency of this fuzzy expert system for prediction of possibility of fatal asthma.

1. Introduction

Inadequacy of medical specialists in developing countries has eventuated in decline of quality of life of many patients. Settling this inefficacy of medical services using the education of human resources is a time-consuming and costly solution that may result in increasing morbidity and mortality of patients. The solution of artificial intelligence in medicine has brought many advantages in diagnosis, management and prediction of diseases.[1] Many intelligence systems have been developed in order to improve health care, reduce cost of treatment, and enhance quality of life, etc. these systems are used of various aspects of AI such as image processing, neural networks, expert systems, and fuzzy logic.[2] The history of applications of expert systems begun by Mycine[3] implies their efficiency in many branches of medicine. Fuzzy technique that is translated as a computing with words by Zade[4], enhances the validity and performance of fuzzy expert systems comparison with expert systems.[5] Expert Systems based on the purpose of development can be classified in 8 categories in medicine.[6] These categories include Predicting and prognosis, Diagnosis, Design, Planning, Monitoring, Treatment, Instruction and teaching, Control and management, and Simulation.

Intelligent systems have main role in diagnosis and management of lung diseases such as asthma. Asthma is a chronic lung disorder with three signs as chronic inflammation, hyper responsiveness, and reversible obstruction of airways that its prevalence is estimated between 1.4-27.1% in the world.[7] There is convincing evidence

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concerning the increasing rate of asthma in Iran.[8] Since asthma as a chronic disease can not heal up, control is the final objective of asthma treatment. Fatal asthma is more common in patients with higher degree of severity, although sudden and unexpected death in patients with mild severity and well-controlled asthma has been occurred.[9] Patients that are in special condition such as continuous exposure to irritants or day-to-day variability in airway obstruction are at risk of life threatening exacerbations that may lead to fatal asthma. Examination of asthmatic patient that are died because of acute or sudden exacerbation may result in finding some important risk factors involving these patients. Considering the risk factors gets a better understanding of variables helping physicians/patients in prediction and prevention of fatal asthma. Regarding the high prevalence of asthma and consequence of mortality and morbidity, some intelligent systems have been developed to mange asthma disease. These systems based on their purposes of application in hospital or primary care setting (offline or online) can be classified in three categories[13] as diagnosing or contribute to diagnosing (such as Fuzzy rule based system for analyzing the obtained result of spirometry tests (FEV1 and FVC)[10]), control management and training (such as presenting a web based asthma tool that significantly enhances information and awareness of users[11]), and prediction (such as predicating pediatric asthma admission in Barbados using neural network[12]).

This paper focuses on the development and testing a fuzzy expert system for prediction of fatal asthma. Because a sudden and unexpected death in patients with mild severity and well-controlled asthma may be occurred, Identification of patients with the risk of fatal asthma can help physicians and patients to adapt appropriate therapeutic approaches and as a result decreases the possibility of asthma mortality. The knowledge constructed the knowledgebase (rule-based) of this system has been generated using indirect approach.[14] Insufficiency of medical records and inexistence of electronic database made the direct approach inefficient approach for developing this system. Fuzzy technique is used for representing uncertain values in fuzzy antecedents and fuzzy consequences. Methodology is used for developing this system is explained in the next section. Section 3 contains the result of system testing. Finally the conclusion of this paper is presented in section 4.

2. Methodology

The methodology of this system includes the processes of knowledge acquisitions, knowledge representation, system testing, and system maintenance.

2.1. Knowledge acquisition

The process of knowledge acquisition consists of five parts as recognize, collect, interpret, analysis, and design. The output of this stage is general inference network. Two groups of system's users (asthmatic -patients and asthma physicians) are participated in this process. Physicians perceive the disease from the low level and consider important details such as the mechanism and pathology of asthma, but patient view it from high level concerning on major consequences of this disease such as chest tightness. As a result considering both views is very important for building knowledgebase. Latent sources such as books, papers, and medical websites are used as

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complement sources. Regard to the output of this stage, the important variables is identified as follow:

- Viral infection: viral infection has a main role in asthma exacerbation and asthmatic patient hospitalization. The crisp value of this variable is determined by user (patient/physican) as Yes (existence) or No (inexistence).
- Exposure to irritants (passive smoking) and allergens*:* Continues exposure of atopic children to house dust mites is an important risk factor of acute asthma attack that may lead to Respiratory Arrest Imminent. This crisp antecedent provides user with two choices as Yes (continues/frequently exposure) or No (Seldom exposure).
- Duration of asthma: Patients with longstanding asthma, abnormal lung function, or day-to-day variability in airway obstruction are at risk for exacerbation that may lead to fatal asthma. Values of antecedents represented as crisp inputs including more than two years and less than two years.
- Response to treatment: this variable considers the status of asthmatic lung to short term medicine such as salbotamol. This variable contains uncertainty in its assigned linguistic values (fair, rather poor, poor) to it.
- Instability of asthma: if the degree of instability of asthma is high, the possibility of fatal asthma increases. This variable is measured using two variables as Peak Expiratory Follow (PEF) and number of severe exacerbations that result in hospitalization. The result of PEF as laboratory data deals with difficulties such as incompleteness, inaccuracy and inconsistency. As a result patient with the result of lab data just on border line could not be defined certainly and clearly as a normal or abnormal. So this variable contains inherent uncertainty.
- Degree of nocturnal symptoms: This variable evaluates the status of asthmatic patient by considering linguistic values as never, seldom, sometimes, often, and frequently. Patients with higher degree of this variable have higher possibility of fatal asthma.
- Degree of intensity of current treatment: Considering the dose of current treatment included short-term and long-term inhaler is a major indicator for evaluation level of asthma control. Poor level of asthma control can be an indicator of fatal asthma. The doses of consumed asthma medicine especially rescue b2-agonist vary from patient to patient because of exposure to different irritants or allergens, so accessing to precise value based on prescribed category by physician seems impossible. As a result, this variable has an internal uncertainty. Intensity of current treatment in this system is evaluated using three variables of Short B2-agonist, Corticosteroid took as long term medicine, and Additional controllers.
- Degree of intensity of exacerbation*:* Acute exacerbation of asthma is not always accompanied with severe respiratory symptoms. Even in the presence of significant bronchial obstruction, wheezing may be absent. However, the patient has other clinical feature such as cyanosis, drowsiness reflecting the acute status. The signs indicate the respiratory arrest imminent that may lead to fatal asthma. The variable of intensity of exacerbation can be evaluated using the following variables: Status of Breathless, Status of Wheeze, Status of Alertnes, Status of respiratory rate, Status of Take in, Status of pulse/ min, Value of PEF after initial bronchodilator, Value of paCO2 , Value of SaO2%

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(on air). Values assigned to this variables contain uncertainty that would be reflected in knowledgebase by fuzzy technique.

- Peripheral blood eosinophilia: studies suggest that peripheral blood eosinophilia greater than 0.453109 per liter increases the relative risk of fatal asthma more than sevenfold. The crisp value of this variable is determined by user as Yes (>0.453109) or No (=<0.453109).

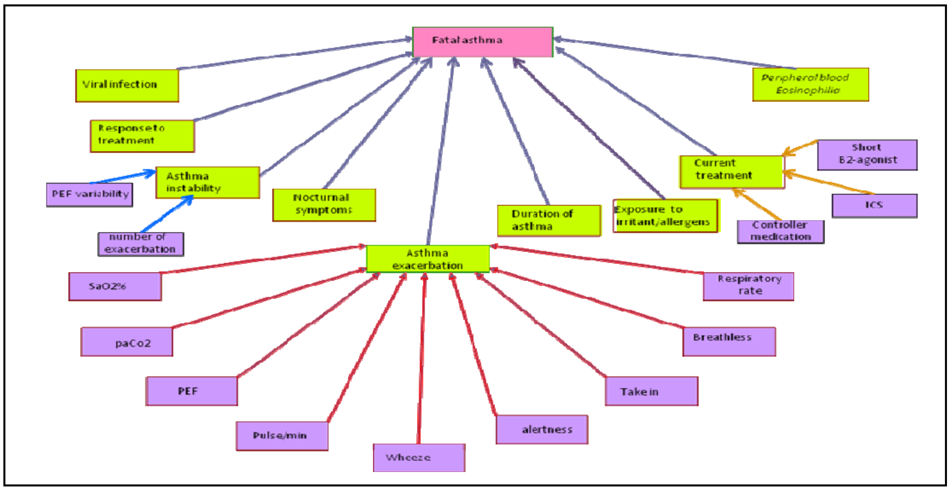

Figure 1: general inference network of variables of fatal asthma

2.2. Knowledge Representation

Techniques are involved in knowledge representation of fatal asthma are General inference networks, production rules, representing uncertainty, and designing system's inference engine.

2.2.1. General inference network

General Inference Networks (GIN) provides a graphical representation of inputs and outputs drawn as nodes. The supporting relationship between input and output are considered as links. Figure 1 depicts the GIN of Variables indentified in the stage of knowledge acquisition.

2.2.2. Production rules

Various combination of inputs and output in GIN (figure 1) are formed the production rules of the system. These rules are generated using interview techniques, task performance and protocols, and questionnaires and surveys. Some examples of production rules are presented in appendix A.

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2.2.3. Presenting uncertainty

Knowledge acquisition (intuition and judgment), Knowledge representation, and incomplete information are sources of uncertainty for representing knowledge of fatal asthma. Fuzzy logic is used in this fuzzy expert system to answer three questions including how to present linguistic and numeric values?, how to combine two or more piece of uncertain data?, and how to design inference engine using uncertain data?.

Identification of fuzzy sets of uncertain variables is calculated by asking the physicians for determining the points with (MF=0) and points with (MF=1). These two points are connected together making triangular or trapezoidal membership functions that are common in representing fuzzy sets because of their computational efficiency [15]. The uncertain variables are represented as follow:

- Response to treatment: Table 1 represents the linguistic values and fuzzy intervals of nocturnal symptoms. The membership function of fuzzy sets related to linguistic values is depicted in figure 2.

Table1: linguistic values and fuzzy intervals of response to treatment

Linguistic values of nocturnal symptoms	Fuzzy intervals
Fair	5-9
Rather poor	3-7
Poor	0-5

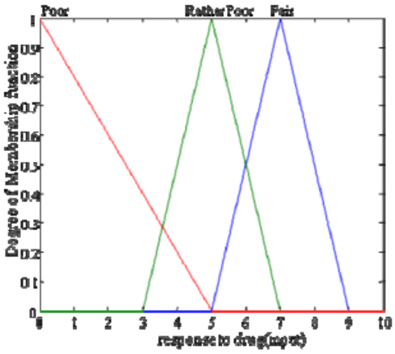

Figure 2: membership functions of variables of response to treatment

- Degree of asthma instability: Table 2 represents the linguistic values of PEF and severe exacerbation as input variables considered for calculating the output variables of degree of asthma instability. Figure 3 represents a schematic view of rules of asthma instability. Membership functions of these linguistic values are depicted in this figure 2 too.

Table 2: linguistic variables and fuzzy intervals of asthma instability

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	Variables	Categories	Fuzzy intervals
input	PEF	Mild	9-25
		Moderate	15-35
		Severe	25-60
input	Severe exacerbation	None	0
		More than one	0-10
output	Degree of asthma instability	Low	0-2
		medium	1-4
		High	2.5-10

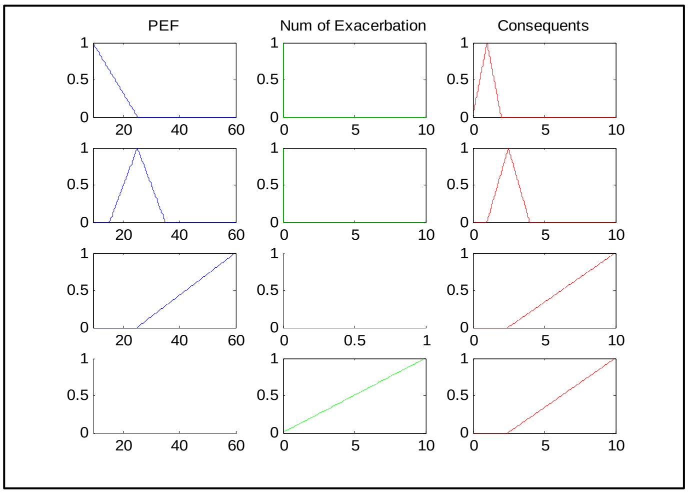

Figure 3: Schematic view of rules and membership functions of asthma instability

- Degree of intensity of current treatment: Table 3 represents the linguistic values and fuzzy intervals of current treatment. Figure 4 depicts the schematic views of rules related to the rules evaluating the degree of intensity of current treatment. Membership functions of these rules are depicted in this figure too.

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Table 3: linguistic values and fuzzy intervals related to current treatment.

	Linguistic variables	Linguistic value	Fuzzy intervals
Inputs	Ba = B2-agonist (weakly)	Low	0-0-3
		Medium	2-10
		High	5-30
	ICS = corticosteroid	None	0
		Low	4-9
		Medium	8-18
		High	17-100
	CM = Controller medication	None	0
		Low	1
		medium	1-2
		High	2-10
Output	Current Treatment	Very low	0-05
		Low	05-1
		Medium	.5-1.5
		High	1.5-10

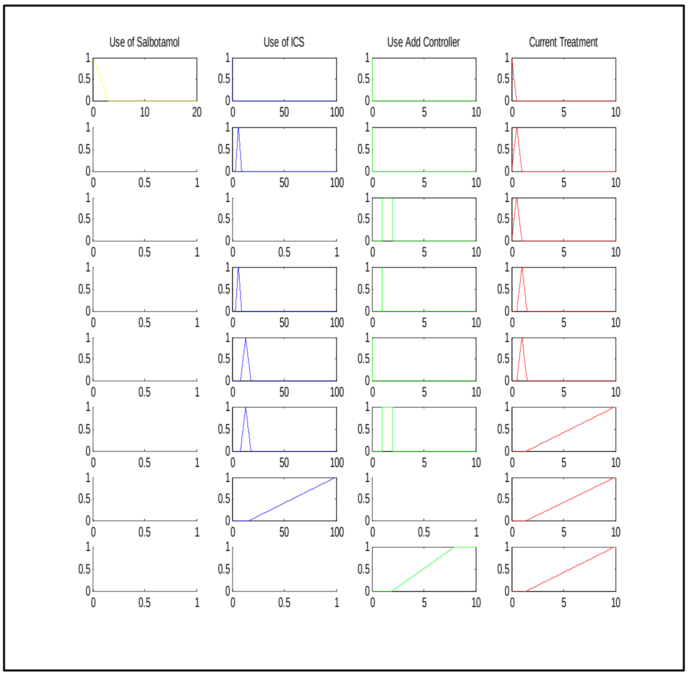

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Figure 4: Schematic view of rules and membership functions of current treatment

- Degree of nocturnal symptoms*:* Table 4 represents the linguistic values and fuzzy intervals of nocturnal symptoms. The membership functions of linguistic values are represented in figure 5 too.

Table 4: linguistic values and fuzzy intervals related to nocturnal symptoms

linguistic value	fuzzy interval
N=Never	0-1
Se=Seldom	0-4
So=Sometimes	1-7
O=Often	4-12
F=Frequently	8-16
A=Always	12-30

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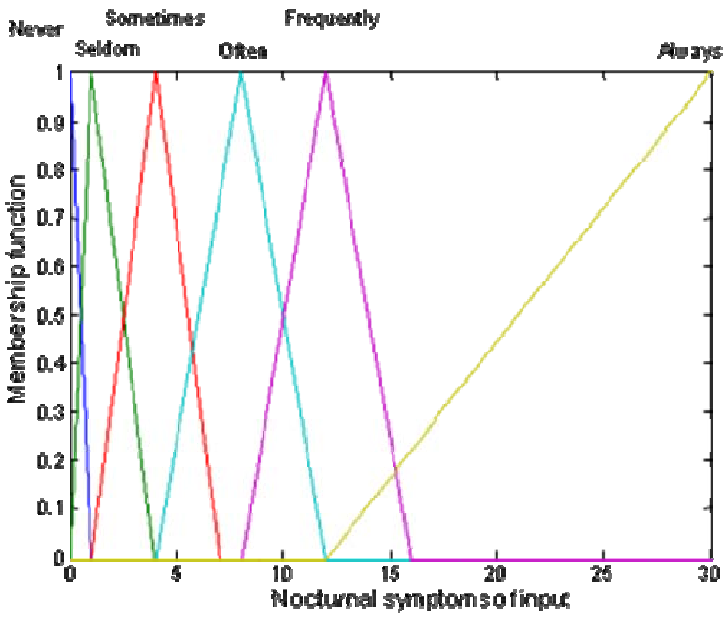

Figure 5: Schematic view of membership functions of variables of nocturnal symptoms

- Degree of asthma exacerbation: this variable is consequent of rules which their antecedents are presented in table 5. This table contains linguistic values and fuzzy interval of these variables too. Figure 6 presents the schematic view of these rules and membership functions of related linguistic values.

Table 5: linguistic values and fuzzy intervals of rules related to degree of asthma exacerbation

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S.N	*Exacerbation's variable*	*Linguistic variable*	*Linguistic value*	**Fuzzy interval**
1	input	Bl =Breathless	Mild	0-3
			Moderate	2-7
			Severe	5-10
2		Ts=Talks in status	Sentences	0-3
			Phrases	2-7
			Words	5-9
			Letter/cannot speak	8-10
3		Al=Alertness	Normal	0-3
			agitated	2-7
			Drowsy or confused	6-10
4		RR=Respiratory Rate	Mild	0-3
			Moderate	2-6
			Severe	4-10
5		W=Wheeze	With out wheeze	0-1
			Mild	0-4
			Moderate	2- 7
			Severe	6-10
6		pulse/ min^3	Mild	0-3
			Moderate	2-7
			Severe	5-8
			Bradycardia	7-10
7		PEF after initial bronchodilator		
			80% -100	75-100
			60_80%	55-85
8		$paCO_2$	< 45 mm Hg	20-45
			> 45 mm Hg;	44--100
9		$SaO_{2\%}$	> 95%	93-200
			91-95%	88-100
			< 90%	92 -40
10	Output	DE=Degree of exacerbation		
			Mild	0-3
			Moderate	2-6
			severe	5-8
			Respiratory Arrest Imminent (RAI)	7-10

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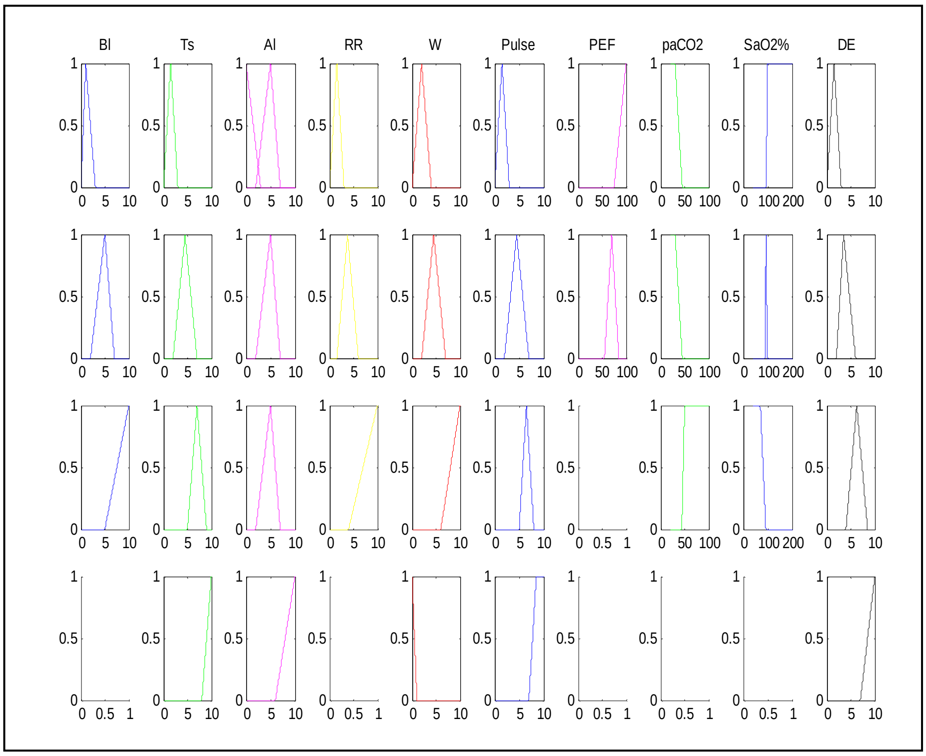

Figure 6: schematic views of rules and membership functions of linguistic values of degree of asthma

2.2.4. System inference engine

Mamdani inference engine is used for parallel processing using maximum and minimum operations. The mechanism of centriod is used for deffuzification of output fuzzy set.

2.2.5. System output

The output of this system presents the possibility of fatal asthma in a graduation from very high to very low in terms of possibility measured in continuum (0-10). These outputs are categorized in five classes presenting the status of patients as a risk of fatal asthma. These classes include very low (0-1), low (1- 3), medium (3-5), high (5-7), and very high (7-10).

3. System evaluation

The performance of this system is evaluated at asthma, immunology, and allergy center of Emam Komani Hospital. The results of 10 asthmatic patients tested by this system are presented in table 6. Comparison the output of this system with asthma physicians'

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opinions (table 6) draws the good performance of this fuzzy expert system. These data are collected based on interview with asthmatic patients in hospital emergency and asthmatic patients referring for periodic check up. This system has been provided just as a prototype, so its development needs the investment of hospitals and research institutes. Extension of application of this system as a web-based or offline system at hospitals, or primary care setting can decrease mortality of asthmatic patients.

Table 6: the result of the testing related to fuzzy expert system of fatal asthma

Variables Patient	**VI[1]**	**EI[2]**	**DA[3]**	**RS[4]**	**IA[5]**	**SNS[6]**	**DCT[7]**	**DIE[8]**	**PBE[9]**	**System output**	**Physician's Evaluation**
Patient1	Yes	Yes	5 year	Poor	....	16	.7	7.9	Yes	Fatal asthma	Intensive care
Patient2	No	Yes	1 year	Fair	6.98	14	5	9.03	…..	Fatal asthma	Intensive care
Patient3	No	Yes	5 year	Fair	2.24	24	5.03	….	….	Fatal asthma	Intensive care
Patient4	No	No	3 year	Fair	7.1	8	1.4497	7.2	Yes	Fatal asthma	Hospitalizaton
Patient5	No	Yes	4 year	Poor	6.43	10	6	6.25	….	Fatal asthma	Intensive care
Patient6	No	Yes	6 month	Fair	6.43	8	2.08	…..	….	High	Additional controller and special care
Patient7	Yes	No	1 year	Fair	2.24	5	4.08	4.5	….	Medium	Additional controller
Patient8	No	Yes	2 year	Good	….	2	1.7	1.5	No	Very low	Stable status
Patient9	No	No	3 year	Good	1	3	1.69	3.8	….	Low	Stable status
Patient10	Yes	Yes	9 month	Good	1	2	5	1.2	No	Very low	Stable status

VI[1]= Viral Infection; EI[2]= Exposure to irritant and/or allergen; DA3= Duration of Asthma; RS[4]= Response to sulbotamul,IA[5]= Instability of Asthma; SNS[6]= status of Nocturnal Symptoms; DCT[7]= Degree of Current Treatment; DIE[8]= Degree of Intensity of Exacerbation; PBE [9] = Peripheral Blood Eosinophilia; N[10]= neutrophil

4. Discussion

Fatal asthma as a sudden consequence of asthma threat the life of asthmatic patients in every level of severity and even in patients with controlled asthma. As a result, prediction the possibility of fatal asthma can contribute the physicians and patients in order to adopt suitable strategy to prevent the imminent consequences. Fuzzy expert system designed in this paper can bring this prediction for patients.

Outputs of this system are represented by two main categories: lower than 5 and more than 5. The category of more than 5 presents patients with the high possibility of fatal asthma that usually include patients with the history of high degree asthma exacerbation. Category of Lower than 5 include patients with low possibility of fatal asthma. These patients are in good conditions regarding the considered variables in this system.

To evaluate the results of this system, 10 patients have been interviewed. The patients' records were not applied for testing this system because the data of records were incomplete. These patients referred to the Emam Khomaini Hospital, 3 patients have high asthma exacerbation, 2 patients have history of hospitalization because of asthma, and five were in good condition while referring for monthly checking. The results of this system in comparison with physicians are proposed in the table 6.

The value of some variables such as esonophile are not available in the table of result tests(table 6). In regard to the modular-base of this system and parallel processing, the unavailability of one variable has not significant effect on the result of

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this system. The result of this system can be checked using more data to get the performance of this system.

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Appendix
Some examples of system's rules

1) Example of rules of asthma exacerbation

If
Breathless is Moderate (Taking Prefer sitting)
AND talks in is Phrases

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AND Alertness is agitated
AND Respiratory rate is Moderate
AND Wheeze is moderate
AND Pulse/ min^3 is moderate
AND PEF after initial bronchodilator 60_80%
AND $paCO_2$<45
AND $SaO_{2\%}$ (on air) 91-95%
Then
Exacerbation is Moderate

2) Example of rule of asthma instability
If
The PEF is severe
Then
Instability is high

3) Example of rule of Current treatment

Inhaled β - agonist $\leq$ 2 times daily
Without use corticosteroids and another controller
Then
CT is very low

4) Example of rule of fatal asthma
If
Asthma's child takes more than 2 years
And
Response to drug is poor (more than 5)
Then
Asthma is near fatal