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Research Article

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Forecasting Surgical Outcomes Using a Fuzzy-Based Decision System

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Abstract

Background and Objectives: The kidneys of chronic kidney disease (CKD) patients do not have enough function and hemodialysis (HD) is a common procedure for their treatment. HD requires vascular access surgery (VAS) and arteriovenous fistula (AVF) is a low-complication method in VAS. However, different rates of AVF failure have been reported worldwide which can cause repeating surgeries and patient hospitalization. The goal of this study was to provide a system with the ability to predict VAS outcomes to reduce failures of surgeries.

Methods: The data of created AVF for 195 CKD patients – consisting 131 males (67.18%) and 64 females (32.82%), and aged from 15 to 87 years - were studied. Our provided system is based on "Fuzzy Inference System" (FIS) and learns rules by extracted results of decision tree algorithm.

Findings: The number of diabetic patients was 73 and 117 persons had hypertension. Their hemoglobin range was 4.9 to 16. Their systolic blood pressure (BP) and diastolic BP were in the ranges [95-230] and [60-120], respectively. Using provided fuzzy control system, these results were investigated: (i) When the systolic BP increases, the AVF maturation improves (ii) In the young patients, the rate of AVF failure is higher than older patients; (iii) Growing patient from "young" to "middle-aged" causes switching from "AVF failure" status to "late maturation"; (iv) In aged patients, high systolic BP with low diastolic BP, shifts from "late" AVF maturation to better statuses namely "good" and "excellent".

Conclusions: Using FIS can forecast surgery outcomes and thus reduce risk factors of patients. In the present developed fuzzy system, surgeons can configure the risk ranges of patient's parameters before vascular surgery and configure changeable factors based on estimating postoperative outcomes.

Keywords: Fuzzy inference system, Data mining, Postoperative outcomes, Vascular access surgery.

Background and objectives

A diagnosis system is one that is capable of identifying the nature of a problem by examining the observed symptoms (the input of the system) and to produce a diagnosis report with or without an explanation or justification (the output of the system). In many applications of interest, it is desirable for the system and quite necessary, to not only identify the possible causes of the problem but also to offer suitable solutions (recommendations) to remediate the anomalies occurred[1].

Chronic kidney disease (CKD) is a condition in which the kidneys are damaged and cannot filter blood as well as possible. In advanced stage of CKD known as end-stage renal disease (ESRD) kidney functions are reduced very severely. The prevalence of CKD is increasing around the world. According to recent statistics of National Kidney Foundation (NKF), there are 26 million CKD patients in the United States at 2012.[2] In Iran the prevalence and incidence of ESRD is 378 per million populations (PMP) and 59 PMP, respectively[3] and most ESRD patients have been treated with dialysis.[4]

Hemodialysis (HD) treatment is the most common procedure which is performed for ESRD patients and HD requires permanent vascular access (VA) as an important aspect.[5] Arteriovenous fistula (AVF) is first VA choice based on the reduced associated complications, morbidity and mortality compared with other methods; also AVF has superior survival rate (estimated at 90% after one year) than other VA .Using AVF is recommended by guidelines and its usage is reported as 67-91% many western countries in recent years.[7] Prosthetic AV grafts, while also preferred to central venous catheters, are generally reserved for use in patients with inadequate native vasculature as they have worse long-term patency and increased rates of infection compared with native fistulae.[8] Nonetheless, AV fistulae are not without their own

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complications, including thrombosis, infection, aneurysm, seromas, steal syndrome, heart failure, and bleeding complicating the placement algorithm.[9] Detecting effective factors of VA failure, can help surgeons for managing this process, as replacing another VA method for risk patients. Data mining approaches can be used for determining the risk factors of early AVF failure[10, 11] and predicting risk factors of surgeries.[12,13] In present study we are combining data mining techniques with fuzzy inference system (FIS) for the first time, which can predict and help to acting, controlling and forecasting VA surgery outcomes.

Materials and Methods

Demographic Data of ESRD in Iran

Iran is the most populous country in the Middle East, with a population of approximately 75 000 000 and covering an area of 1.65 million km^2. According to the report of the Management Center for Transplantation and Special Diseases (MCTSD) of Iran, the prevalence and incidence of ESRD have significantly increased in recent years; however, they are still low compared with developed countries.[14]

The total number of patients with ESRD undergoing renal replacement therapy (RRT) in 2007 was 32 686, which denotes a prevalence of 435.8 PMP. This number is very high compared with 1997, 2000 and 2006, when the prevalence of ESRD was 137 PMP, 238 PMP and 357 PMP, respectively. The incidence of ESRD patients also seems to be increased, from 13.82 PMP in 1997 to 49.9 PMP in 2000 and 63.8 PMP in 2006. It is possible that the increase is due to the increased recognition of the disease due to the increase in the number of HD centers (150 in 1997, 227 in 2000 and 316 in 2006), kidney transplantation centers, transplantations (22.8 PMP in 1997 to 26.5 PMP in 2006) and nephrologists in our country. Also, the number of patients on HD increased from 587 (106.7 PMP) in 1991 in Tehran to 12 500 (179 PMP) in 2006.[15-18] Moreover, the statistics of ESRD incidence and prevalence in years 2008-2012 is published by United States Renal Data System.[19]

Statistical Analyses

In this review, the patients' information were recorded including age and gender, measures of medical history before AVF creation such as hemoglobin and diabetes mellitus, and potential risk factors such as blood pressure (BP) during operation. The maturation time (MT) was considered as the time between the AVF creation and accessibility for HD. All of patients were referred by nephrologists for AVF creation during years 2010-2012. The data of 195 CKD patients who were under HD using AVF as their VA. The data consist of 2 groups due to AVF status: (i) one group has 87 records with matured AVF for dialysis; according the long of MT, we classified these patients into three classes as: "excellent" (3-4 weeks), "good" (5-7 weeks) and "late" (8-10 weeks).[20] (ii) In another subset of data, there are 108 patients with AVF failure surgery ("None-Mature").

There were 131 males (67.18%) and 64 females (32.82%) introduced into this study. Patients' age ranged from 15 to 87 years. The number of diabetic patients was 73 and 117 persons had hypertension. Hemoglobin range was from 4.9 to 16. The "systolic_BP" and "diastolic_BP" ranged [95-230] and [60-120], respectively.

Rule Extraction by Data Mining

As Rezapour et al showed in a research,[21] using data mining approaches can provide less risk methods of surgeries for reducing complications and failure results. Moreover, researchers can measure associations between risk factors and outcome of surgeries, and subsequently detect novel adverse effects, using data mining approaches; For instance, lower risk of AVF failure has been founded in hypertensive HD patients by recent studies.[22,23]

We used "Decision Tree" (DT) which is one of "classification" methods in data mining predictive approaches.[24,25] Running the DT namely W-J48 from supervised learners of Weka collection from rapidminer, the initial rules between parameters were extracted and we obtained the following rules, which will be used in next processing step (Table 1):

Fuzzy Inferences System

In this stage, we run the "Fuzzy Inference System" (FIS) editor, which is available using the command "fuzzy" in MATLAB, and define four input variables with the ranges that we mentioned at "statistical analyses" section, as Figure 1:

Moreover, for any input variable we defined a Gaussian membership functions (MF) due to extracted rules in Table 1; for example, for the "Age" variable we considered three fuzzy parameters: "young: [15-45]", "middle: [45-63]" and "Aging: [63-87]".

Similarly, for the "Systolic_BP" variable we defined Gaussian MF with parameters: "up to 115", "(115-130]" and "after 130". Moreover, for "Diastolic_BP" we had: "about 60", "(60-75]" and "after 75". Likewise, we considered "Hemoglobin" as: "up to 8.5", "(8.5-9.1]", "(9.1-10.6]", "(10.6-11.6]" and "after 11.6". Finally, we use "trimf" for the output variable namely "AVF-Status" with parameters as: "Not-Mature", "late", "good" and "excellent", according to

Table 1. The Extracted Rules From Decision Tree

Number	Details of Rules
(1)	If (Age <= 45) Then AVF-Status= "**Not-Mature**"
(2)	If (Age>45) and (Systolic_BP<=115) and (Hemoglobin<=8.5) and (Diastolic_BP<=60)Then AVF-Status= "**good**"
(3)	If (Age>45) and (Systolic_BP<=115) and (Hemoglobin<=8.2) and (60<Diastolic_BP<=75)Then AVF-Status= "**late**"
(4)	If (Age>45) and (Systolic_BP<=115) and (Hemoglobin<=10.6) and (75<Diastolic_BP)Then AVF-Status= "**Not-Mature**"
(5)	If (Age>45) and (Systolic_BP<=115) and (Hemoglobin>10.6) Then AVF-Status= "**good**"
(6)	If (Age>63) and (Systolic_BP>115) and (Diastolic_BP<=60) Then AVF-Status= "**excellent**"
(7)	If (Age>45) and (Systolic_BP>115) and (Diastolic_BP>60) and (Hemoglobin<=9.1) Then AVF-Status= "**Not-Mature**"
(8)	If (Age>45) and (Systolic_BP>115) and (60<Diastolic_BP<=75) and (11.6<Hemoglobin<=12.2) Then AVF-Status= "**excellent**"
(9)	If (Age>45) and (Systolic_BP>130) and (75<Diastolic_BP) and (9.1<Hemoglobin) Then AVF-Status= "**Not-Mature**"

the defined classes in "Data" section.

Creating Rules in FIS

Now, we are about to create rules in FIS (which is available using shortcut keys Ctrl+3). For this purpose, we will entry the following rules, as well as rules of Table 1.

Results

Measure Fuzzy Outcomes of Surgery

All of rules are viewable (using keys Ctrl+5) and the surgeon can move the indicator line (with red color) and see what will happen. First, we consider the minimum values of any variable except "Age"; as it is resulted from Figure 2, "when patients are young, the AVF failure (Not-Mature) is high"; The right column of Figure 2, the right triangle shows the status of "Not-Mature" and other side triangles indicate statuses "late", "good" and "excellent" (in the left triangle), respectively.

Now we change the indicator line of "Age" to select "Middle-aged" patients; we see that the color of the previous filled triangle (in Figure 3) decreases:

Meanwhile, on the other hand, part of the two other triangles (corresponding with "late" and "good" maturation) have begun to fill up the blue color; also the thick indicator (in the right lowest rectangle) moves to the left status (Figure 4).

Finally, running surface view (by Ctrl+6 keys) we have the three-dimension chart as Figure 5, that clearly states the relation between "early AVF maturation" and "higher the patient's age" with "increase Systolic_BP":

Measure Fuzzy Outcomes of Surgery

The extracted patterns which are useful in forecast results of surgery are shown in Table 2.

Discussion

Since introducing fuzzy logic concept by Zadeh in 1965,[26] it has been widely used for modeling complicated systems suffering from inherent imprecision. The first studies that used artificial neural network (ANN) were to predict HD factors in 1998.[27] The controlled BP such as outcome of a fuzzy controller in HD patients were studied in 2009.[28] Azar has presented a Takagi–Sugeno–Kang FIS for equilibrated urea concentration prediction.[29] More details are referred by Rezapour and Shirdel.[30,31]

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology, which was proposed in 1975 by Ebrahim Mamdani.[32] In other medicine fields, there are various research using ANN and fuzzy

Table 2. the extracted patterns from fuzzy inference system (FIS)

Number	Details of Rules
(1)	From fuzzy charts of figure 2, we conclude the pattern (1) (as rule (1) of table 1): {In the "Young" patients "AVF failure" is higher than older patients}
(2)	Moreover, comparing figures 3 and 4 shows an improving pattern (2): {Growing patient from "Young" to "Middle-aged"} → {Switch from AVF failure to "late Maturation"}
(3)	Also, figure 5 shows that in aging patients we pattern (3) says the effective role of high systolic BP: {In "Aging" patients: High "Systolic_BP" by low "Diastolic _BP"} → {"good" and "excellent" maturation"}

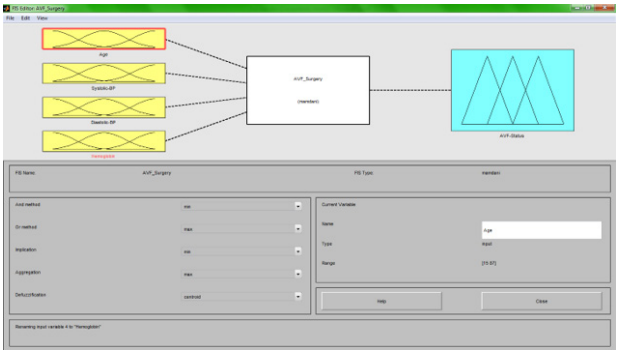

Figure. 1. Defining 4 Input Variables With Their Ranges in the FIS Editor.

Figure 2. Rule viewing of “Young” patients; Denote that in the right column, the right blue triangle shows the status of “Not-Mature” and other side triangles indicate statuses “late”, “good” and “excellent”, respectively.

Figure 4. Improving AVF status from “late” to “good” and “excellent” maturation with high “Systolic_BP” with low “Diastolic_BP”.

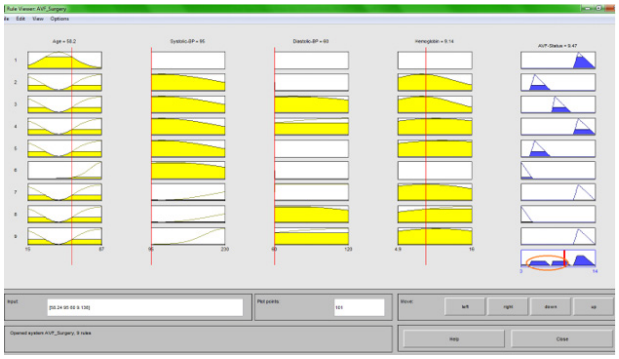

Figure 3. For “Middle-aged” patients, part of the two other triangles (corresponding with “late” and “good” maturation) have begun to fill up the blue color.

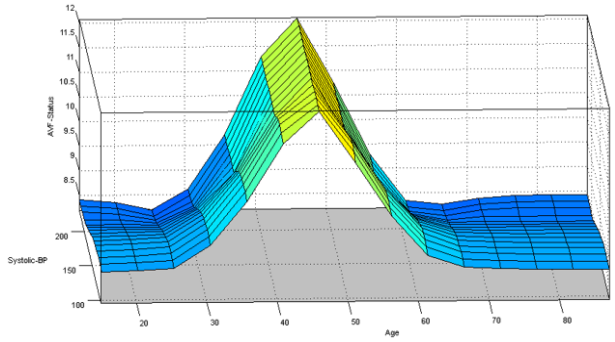

Figure 5. Surface view states the relation between “early AVF maturation” and “higher the patient's age” with “increase Systolic_BP”.

methods. For instances, Hashemian et al applied multi-layer perceptron ANN model to predict kidney transplant survival and compare cox regression models, and concluded that “ANN model has better prediction ability”.[33] Torshabi has implemented a model based on adaptive neuro-fuzzy inference system (ANFIS) and came to the result that ANFIS is still robust to track tumor motion more reliably by remarkably reducing the motion estimation error.[34] Comparing similar research in this field, Guh et al[27] assumed a FIS under consideration with two inputs and one output and with two fuzzy if-then rules of Takagi and Sugeno’s type.[35]

However, our designed FIS has four input variables using Mamdani model with nine if-then rules. Combining data mining results (in training level) and FIS (for inferencing outcomes) concludes the patterns that are useful in forecast results of surgery. Moreover, there is some improver methods which hint transferring classes (such as “Not-Mature” or “Late”) into better classes (such as “good” and “excellent”).

Conclusions

FIS can help forecasting medicine outcomes and so reduce risk factors that patients are involved with them. In our developed fuzzy system, surgeon can configure the value ranges of input patient’s parameters and check the output results before his or her AVF surgery, based on the real past situations. The main concluded rules in present study are: (i) In the “Young” patients, the rate of “AVF failure” is higher than older patients; (ii) Growing patient from “Young” to “Middle-aged” causes switching from “AVF failure” status to “late Maturation”; (iii) In “Aging” patients, high “Systolic_BP” with low “Diastolic_BP”, move from “late” AVF maturation to improve the statuses namely “good” and “excellent”.

Disclosure

None of the author and coauthors of this paper have any direct or indirect financial relation with the tools mentioned in this research.

Competing interests

The authors declare no competing interests.

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