Medical Journal of Bakırköy

Med J Bakirkoy 2023;19:324-327
DOI: 10.4274/BMJ.galenos.2023.2023.5-9

Research

Adolescent Idiopathic Scoliosis Surgery Decision Making with Fuzzy Model

Adölesan İdiyopatik Skolyoz Cerrahisi Kararında Bulanık Model Kullanımı

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ABSTRACT

Objective: The surgical decision in scoliosis patients exhibits variability based on angle parameters and the characteristics of patients in the adult or adolescent age group. Existing studies demonstrate that the Cobb's angle, particularly in the range of 25-45, shapes the surgical decision depending on the measures and characteristics of the patients. This study evaluated the performance of a fuzzy logic-based decision support system in making surgical decisions.

Methods: A total of 888 patient scenarios were generated in a computer environment, with age, Cobb's, and Risser values. Surgical probability predictions were recorded according to the values in the patient scenarios using rules established by field experts through fuzzy modeling.

Results: Although surgical necessity was found in 28.8% of the patients in the reference model, the model detected it at a rate of 11.6%. The sensitivity of the model was 33.9% [95% confidence interval (CI) 27.8-39.7%], specificity 97.3% (95% CI 95.7-98.4%), positive predictive value 83.5% (95% CI 74.9-90.1%), negative predictive value 78.34% (95% CI 75.3-81.2%), accuracy 78.9% (76.1-81.6%), Youden index 0.308, and area under the curve value 0.654.

Conclusion: Fuzzy logic is a viable method, particularly in situations where boundaries cannot be clearly determined. Considering variables such as Cobb's and Risser in scoliosis surgery, it could be a method to use in the choice of surgery or conservative follow-up.

Keywords: Fuzzy logic, scoliosis, spinal surgery, Risser, Cobb's

ÖZ

Amaç: Skolyoz hastalarında cerrahi kararı açı parametreleri ve hastaların yetişkin ya da adölesan yaş grubu özelliklerine göre değişkenlik göstermektedir. Yapılan çalışmalarda Cobb açısı özellikle 25-45 aralığında cerrahi kararı kişisel özelliklere, ölçümlere ve hasta özelliklerine bağlı olmaktadır. Çalışmamızda bulanık mantık tabanlı karar destek sisteminin cerrahi kararı vermedeki performansını ölçmek amaçlanmıştır.

Gereç ve Yöntem: Bilgisayar ortamında oluşturulan 888 hasta senaryosu yaş, Cobb ve Risser değerleri oluşturulmuştur. Bulanık modellemesi ile alan uzmanlarınca oluşturulan kurallar ile hasta senaryolarındaki değerlere göre cerrahi olasılık tahminleri kaydedilmiştir.

Bulgular: Referans modelde cerrahi gereklilik %28,8 hastada bulunurken model %11,6 oranında saptandı. Modelin duyarlılığı %33,9 [%95 güven aralığı (GA) %27,8-39,7], özgüllüğü %97,3 (%95 GA %95,7-98,4), pozitif prediktif değeri %83,5 (%95 GA %74,9-90,1), negatif prediktif değeri %78,34 (%95 GA %75,3-81,2), doğruluk %78,9 (%76,1-81,6), Youden indeks 0,308 ve eğrinin altındaki alan değeri 0,654 olarak bulunmuştur.

Sonuç: Bulanık mantık özellikle sınırları net belirlenemeyen durumlarda kullanılabilir bir yöntemdir. Skolyoz cerrahisinde Cobb, Risser gibi değişkenler de ele alındığında, cerrahi ya da konservatif takip seçiminde kullanılabilecek bir yöntem olabilir.

Anahtar Kelimeler: Bulanık mantık, skolyoz, spinal cerrahi, Risser, Cobb's

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Cite as: Berikol G, Erdoğan U. Adolescent Idiopathic Scoliosis Surgery Decision Making with Fuzzy Model. Med J Bakirkoy 2023;19:324-327

Received: 31.05.2023
Accepted: 14.09.2023

INTRODUCTION

Adolescent idiopathic scoliosis (AIS), one of the most common types of scoliosis, presents symptoms before adulthood and emerges when the spine angulation of 10° or more. Idiopathic scoliosis, particularly in those over 10 years of age, is a disease that requires treatment because of its progressive nature and its impact on other systems such as the cardiovascular system (1,2).

Physiological factors, such as age, body mass index, bone density, and radiological scales, such as the Risser score, Cobb's angle, and Sanders, determine the progression of the disease and the need for surgery (2). The most determinant variables for diagnosis are the size of the curve and skeletal density. As these are also the most determinant variables of progression, they are used in making the decision for surgery.

Particularly in AIS treatment, having a Cobb's angle of 45° and above, the patient's age leading to an increase in the growth rate of scoliosis, functional limitation, and response to physiotherapy or bracing affects the surgical decision (3). In patients without skeletal maturity, a Cobb's angle of ≥50° is a clear surgical indication, whereas in some immature patients above 45° or in some mature patients ≥50°, surgical indication can still be made (4). The correct surgical decision should be made on a patient-by-patient basis. Performing surgery when necessary can prevent the patient's progression to respiratory and cardiovascular insufficiency, while also protecting the patient against complications such as blood loss, implant insufficiency, and infections. In a systematic review, it was stated that there are still limitations for clinical use in the studies conducted, and there is a need for artificial intelligence studies for spinal curvature prediction (2).

Fuzzy logic is an artificial intelligence model that is based on the "if...then" logic and is carried out with the weighting of the evaluation's membership to clusters with the help of a set of linguistic rules (5). In this context, a variable can be included in more than one class with different weights (6). This method helps in the classification of random variables that are difficult to belong to a certain class. This method, which is used in areas such as engineering and biology, has been studied in many areas of medicine in recent years (7-9).

The study evaluated the performance of the fuzzy logic model in determining the surgical decision for AIS.

METHODS

In our study, the fuzzy logic model was used to make surgical decisions with the variables used in the guidelines. The study methodology involved creating surgical or bracing outputs in an *in silico* model using inputs such as age, Cobb's angle, and Risser score using FuzzyTech 8.21c Professional Edition on Windows 10 (Licence no: Akdeniz University 1000700). The rules and membership functions are shown in Figure 1 and Table 1. The Center of Maximum defuzzification model was chosen because of the clarity of the decision for surgical or conservative treatment. The fuzzy rules related to surgical decisions were made in line with the prediction scores found in the literature and were confirmed by field experts (10-13).

To validate the system model and measure its performance, 888 patient scenarios were created, with Cobb's angles and Risser scores ranging from 23° to 46° according to age between 9 and 16 years and treatment predictions were recorded in the model.

Eighty-one rules (25 partial rules) were generated. The generated example rules are shown in Table 2.

The results of the model were compared with those of the Risser score calculation tools used in literature-based practice, and their performances were tested with sensitivity, specificity, accuracy, and F1 score using the Jamovi 1.6.21 program.

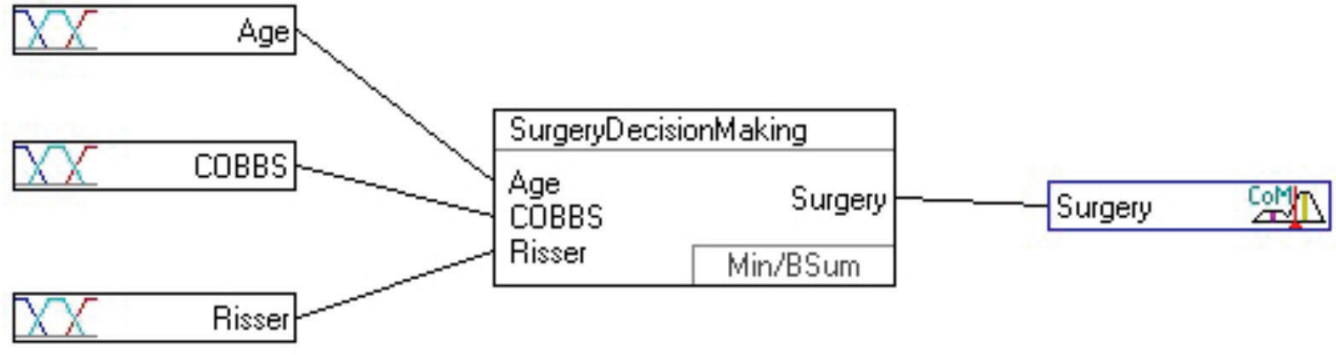

Figure 1. Structure of the fuzzy logic system

Table 1. Variables of input and output

#	Variable name	Type	Unit	Min	Max	Default	Term names
1	Age		Age	0	20	15	Childhood Adolescent Adult
2	Cobb's		Degree	0	100	0	Low Medium High
3	Risser		Scale	0	2	2	Low Medium High
4	Surgery		SurgeryNeed	-1	1	0	Low Medium High

Min: Minimum, Max: Maximum

Table 2. Examples of rules and membership weights. For example, IF age is "high" Cobb's "high", Risser "high", then surgery is "high likely"

Age	Cobb's	Risser	DoS	Surgery
9	11	0	1.0	Low likely
9	12	0	1.0	Low likely
16	42	1	1.0	Intermediate
16	43	1	1.0	Intermediate
16	46	1	1.0	High likely
16	47	1	1.0	High likely

Table 3. Crosstable of the surgery likelihood of reference and model

		Reference score calculators		
		Low	Intermediate	High
Fuzzy model	Low	74	10	0
	Intermediate	370	161	170
	High	2	15	86

RESULTS

In our study, among the 888 patient scenarios, 28.8% (256/888) were potential surgical candidates, whereas the model identified a surgical likelihood of 11.6% (103/888). The cross-table according to the model and reference is shown in Table 3.

The sensitivity of the model was determined as 33.9% [95% confidence interval (CI) 27.8-39.7%], specificity as 97.3% (95% CI 95.7-98.4%), positive predictive value as 83.5% (95% CI 74.9-90.1%), and negative predictive value as 78.34% (95% CI 75.3-81.2%).

The accuracy was found to be 78.9% (76.1%-81.6%), the Youden index was 0.308, and the area under the curve value was 0.654 (Figure 2).

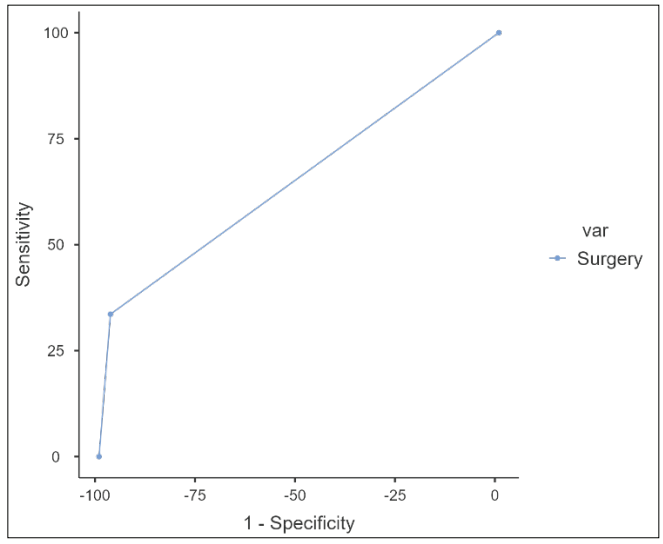

Figure 2. ROC curve of the fuzzy model
ROC: Receiver operating characteristic

DISCUSSION

In our study, traditional calculation models and fuzzy models were compared in a scenario of 888 patients, and it was determined that they could be used in surgical decisions with a specificity of 97.3%. In the review conducted, the top five factors determining the prognosis of scoliosis were curvature speed, skeletal maturity, location of the curvature, age, and menarche status. In our study, age, skeletal maturity with Risser, and Cobb's angle were taken into account (2). Gender was taken as female in reference calculators because it was not stated as a determinant (10,11,13).

In the literature, there are artificial intelligence-based decision support systems for the diagnosis and management of scoliosis. In the fuzzy logic model calculating Cobb's angle in spinal graphs using the Schroth method by Goral

and Kose (14), the accuracy of suggestions for diagnosis and exercises for physiotherapy is 0.98. Again, it has been reported that the prediction of Cobb's angle with image processing and machine learning in the decision of spinal fusion surgery, especially whether it is less than <10°, can predict with an accuracy of 86.23% (15).

As indicated in the literature, ≥50° is suggested to have surgery with a high evidence level regardless of maturity and time, and ≥45° and Risser <2 is suggested to have surgery with a lower evidence level (4). The decision to postpone the surgical option as much as possible varies according to the follow-up of spinal surgeons and patients. Therefore, machine learning has been used in the literature especially for predicting the necessity of surgical intervention, and a decision support system based on random forest has been developed, which optimizes surgical decisions according to the final Cobb's angle estimate using the most predictive variables, Cobb's angle, flexibility, age, and Risser criteria (16). In addition, the progression of curvature was developed with a logistic regression model, and in the prediction made with Cobb's, Menarche, weight, Risser, plasma microRNA, and bone turnover markers, a specificity of 90% and a sensitivity of 72.7% were determined (17).

In addition, a decision support system was developed by working on deciding on surgical treatment using a fuzzy logic-based clustering algorithm on a diagnostic classification with early onset scoliosis classification using age, etiology, Cobb's angle, and kyphosis variables (18).

Our study is preliminary, and the non-use of real patient data limits our study. Further studies require this system to be validated with real-life data. In addition, our model includes other variables, such as growth rate and Sanders. The model results can be improved by adding these criteria.

CONCLUSION

In our study, the use of fuzzy logic modeling in making surgical decisions in AIS with Cobb's, Risser, and age variables emerged as a method that could be used in the selection of surgical patients with high specificity. We believe that by increasing the variables in future studies and validating with real outcomes, the model can achieve a higher accuracy rate.

ETHICS

Ethics Committee Approval: The study does not require ethics committee approval.

Informed Consent: The study does not require patient consent.

Authorship Contributions

Concept: G.B., U.E., Design: G.B., U.E., Data Collection or Processing: G.B., U.E., Analysis or Interpretation: G.B., U.E., Literature Search: G.B., U.E., Writing: G.B., U.E.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declare that this study received no financial support.

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