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A web-based fuzzy risk predictive-decision model of de novo stress urinary incontinence in women undergoing pelvic organ prolapse surgery

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Abstract

Background: Pelvic organ prolapse (POP) and stress urinary incontinence (SUI) are common conditions affecting women's health and quality of life. In 50% of cases, SUI occurs after POP surgery, which is called de novo SUI. Predicting the risk of de novo SUI is a complex multi-attribute decision-making process. The current study made available a Decision Support System in the form of a fuzzy calculator web-based application to help surgeons predict the risk of de novo SUI.

Materials and methods: We first identified 12 risk factors and the diagnostic criteria for de novo SUI by means of a systematic review of the literature. Then based upon an expert panel, all risk factors were prioritized. A set of 232 fuzzy rules for the prediction of de novo SUI was determined. A fuzzy expert system was developed using MATLAB software and Mamdani Inference System. The risk prediction model was then evaluated using retrospective data extracted from 30 randomly selected medical records of female patients over the age of 50 without symptoms of urinary incontinence who had undergone POP surgery. Finally, the proposed results of the predictive system were compared with the results of retrospective medical record data review.

Results: The results of this online calculator show that the accuracy of this risk prediction model, at more than 90%, compared favorably to other SUI risk prediction models.

Conclusions: A fuzzy logic-based clinical Decision Support System in the form of an online calculator for calculating SUI prognosis after POP surgery in women can be helpful in predicting de novo SUI.

Keywords: Expert system; Fuzzy logic; Pelvic organ prolapse surgery; Risk prediction; Stress urinary incontinence

1. Introduction

Pelvic organ prolapse (POP) is one of the most common health problems in women.[1] More than 2000 POP surgeries are being performed each year in the United States.[2] As reported, POP surgery leads to de novo (or postoperative) stress urinary incontinence (SUI) in 16%–51% of cases.[3] Prolapse has been defined as "symptomatic descent of one or more of the anterior or posterior vaginal walls, apex of the vagina or the uterus."[4] Prolapse can be mild to moderate, initially treated using physical therapy such as pelvic floor muscles exercises or pharmaceuticals, or in more severe cases, definitively treated via surgery. By definition, SUI refers to loss of urine during exercise or physical activities such as sneezing, coughing, jumping, or lifting heavy objects.[5] The incidence of urinary incontinence in the female population is more than of males and the prevalence rate of this condition in the elderly population is also over 35%.[1] Female urinary incontinence is usually associated with POP.[4] Costs associated with SUI exceed 10 billion US$ annually.[5] Given that predicting the likelihood of de novo SUI depends upon a range of complex factors, physicians are looking for ways to reduce relevant risk factors and prevent the need for surgical repair, thereby reducing costs associated with surgery and ultimately improving patient rehabilitation outcomes.[6–8] Multiple genetic, physiological, and lifestyle-related factors may also contribute toward female urinary incontinence after POP surgery.[9] Therefore, identification of these risk factors could greatly influence the postoperative prognosis of POP patients in regards to development of de novo SUI.

Of relevance, Decision Support Systems (DSSs) have been introduced as computer-based tools that can help physicians make evidence-based treatment decisions and evaluate outcomes. Accordingly, medical DSSs promise a significant advantage in improving the quality of medical decisions in order to better predict clinical outcomes.[10,11] These systems were first applied to the field of medicine in 1985 to increase the quality and efficiency of healthcare services and to reduce medical errors.[10] Subsequently, DSSs have been shown to significantly improve clinical performance.[12,13] Therefore, designing a risk predictive-decision model for de novo SUI before POP surgery could assist physicians in improving their decision-making process and potentially reduce the need for subsequent surgery.[14,15] Predicting the risk of SUI using urodynamic tests and preventive measures for urinary incontinence have been thus far applied both prior to and concurrently with surgery, but such tests cannot

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predict individual risks in sufficiently accurate manner.[16,17] Therefore, the present study aimed to design a fuzzy system based upon estimates of risk factors and clinical features following a systematic review of clinical studies of women aged 50–80 years with no baseline symptoms of SUI who underwent POP surgery.

1.1. Expert systems and fuzzy logic

Expert systems are computer programs and a branch of artificial intelligence that mimic human-like behavior. These computer programs include algorithms, rules, and data collected from professionals or books that can form the basis of knowledge for an expert system affecting any area of human life and help solve complex problems.[18] Fuzzy logic, first introduced by Lofti Zadeh in 1965, is known as a method responsive to uncertainties. In medicine, it is also used for prognostic models, mostly in the form of risk assessment applications. Additionally, it is useful when subjective patient data must be precisely mapped into a single outcome. From a computer science perspective, computer code consists of 0 and 1, but it is not always sufficient when solving problems to consider only 2 answers of either yes or no. Fuzzy logic thus allows for mapping quantities of different things and functions. In addition to 0 and 1, 2 functions with varying degrees can be correspondingly obtained. Membership functions can be also utilized to represent data, since they are employed to map input into different classifications in a range from 0 to 1.

DSSs include both knowledge-based and non-knowledge-based systems. Knowledge-based clinical DSSs generally contain rules in the form of "if-then." In addition, DSSs and expert systems employ various other methods to aggregate information for decision-making processes. Among these methods is a rule-based fuzzy expert system.[19] All expert systems consist of 3 main parts, including input, an inference engine, and output, as shown in Figure 1. Accordingly, in a fuzzy system, all inputs are deduced using the inference engine, and then outputs are generated. Therefore, one of the most common requirements in the design of rule-based fuzzy expert systems is to correctly utilize expert knowledge and reasoning patterns. Fuzzy expert systems are thus expert systems that help physicians resolve issues surrounding uncertainties, which could help improve physician decisions.[20–24]

1.2. POP and SUI

The International Continence Society has defined urinary incontinence as a "complaint of involuntary loss of urine" and urinary stress incontinence as the complaint of involuntary leakage on effort or exertion, or on sneezing or coughing.[25] POP has been primarily defined as an anatomical change, with prolapse referring to a "falling, slipping, or downward displacement of a part or organ" and pelvic organs referring most commonly to the uterus and/or different vaginal compartments and their neighboring organs such as the bladder and rectum.[26] The prevalence of prolapse is about 50% among middle-aged women, and urinary incontinence is an even more common condition in this age group, making the association between these 2 variables complicated in regards to various etiological factors.[27] In up to 63% of women, POP may coexist with SUI,[28] and the prevalence of SUI following POP surgery is also by 16%–50%. In addition, SUI and POP share many etiological factors including parity, age, ethnicity, increased intraabdominal pressure, estrogen deficiency, smoking, neurological injury, and hysterectomy. In some studies, genetic or intrinsic differences in connective tissues in individuals have been also mentioned as factors leading to urinary incontinence or POP.[29] The incidence of POP surgery ranges from 1.5 to 1.8 per 1000 women per year and with a peak observed in women aged 60–69 years.[30] According to published reports, the lifetime risk of POP surgery women is approximately 7%–11%,[31] and almost one-third of those women will undergo a secondary surgery.[27]

2. Materials and methods

This study was performed in 3 stages as follows. In the first stage, all risk factors and characteristics were determined. In the second stage, these factors were analyzed, modeled, and designed. Finally, in the last phase, this model was evaluated.

2.1. Input risk factors

In the present study, the input knowledge of this system was based upon evidence that was extracted from studies during a systematic review whose publication is pending. Initially, all of the risk factors associated with the possibility of SUI in older women without symptoms of SUI who underwent prolapse

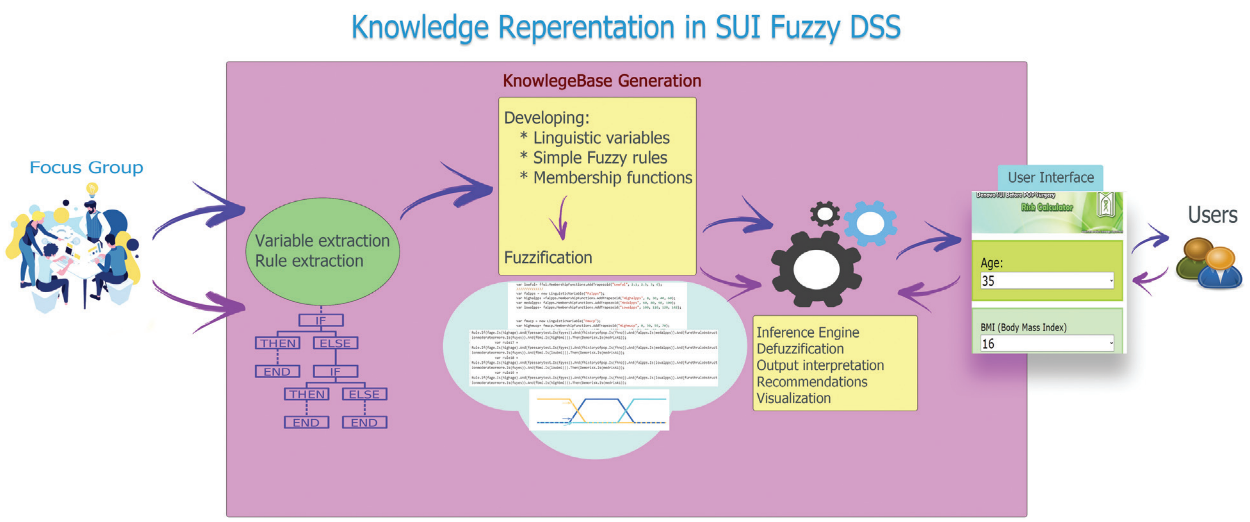

Figure 1. Schematic of the fuzzy system.

surgery included in the systematic review study were extracted. A total of 12 risk factors were identified as suitable for inclusion into a predictive model for the risk of de novo SUI, including demographic information, clinical information, and diagnostic test results such as urodynamic variables. These variables included age, body mass index (BMI), parity, history of diabetes, previous pelvic surgery, maximum urethral closure pressure, functional urethral length, abdominal leak point pressures, lower urinary tract obstruction, pessary test, and urethral obstruction (moderate or more severe).

2.2. Design and modeling

In a fuzzy system, outputs are associated with membership functions that can provide a more accurate result from inputs. In design of this study, models were obtained via a trapezoidal membership function using the DotFuzzy-2.0. It is an open source stand-alone class library.[2] Linguistic variables were defined according to Mamdani's law in this model at 3 levels of low, medium, and high; in the same way, trapezoidal membership functions were used in its modeling. Then, each of the variables was defined with the help of these functions, and consequently, the exact interval value was obtained for each of the variables, as shown in Figure 2. After identifying system inputs to create a knowledge base and extract fuzzy system rules, 232 fuzzy rules were considered based upon the 12 previously identified risk factors. Next, all fuzzy rules were inferred in the Fuzzy Inference System. The Fuzzy Inference System was designed to predict the risk of de novo SUI, which was categorized according to the priority selected in 2 levels. The first level included 137 rules, and the second level was comprised of 95 rules. It should be noted that the results of this study are based upon the system's recommendations and the findings of data from women who had previously undergone surgeries. An example of these rules is shown in Appendix 1, Table 1, http://links.lww.com/CURRUROL/A5. Finally, the design of this model was completed. A fuzzy logic-based clinical DSS was then designed as a web-based graphical user interface that presents the expert's argument in the form of a decision model. This web-based graphical user interface was designed in the ASP.NET Core environment using C# programming language, as shown in Figure 3.

2.3. Evaluation

To evaluate the performance of the fuzzy expert system, retrospective data from medical records of 30 patients admitted to the urology department of a teaching hospital who were undergoing POP surgery from June 2018 to June 2019 were reviewed. The data were then analyzed to compare the results of the expert system and those found in the medical records. The data assessor was blinded to the system records. Accuracy, specificity, and sensitivity of the prediction model were determined based on the analyzed data.

Sensitivity = TP (True Positive)/(TP + FN [False Negative])
Specificity = TN (True Negative)/(TN + FP [False Positive])
Accuracy = (TP + TN)/(TP + FP + TN + FN)

3. Results

In order to prioritize risk factors, all of the risk factors were classified into 2 groups according to a systematic review of evidence-based studies and subsequently by an expert panel. The list of the most important risk factors of these 2 levels are shown in Appendix 2, Table 2, http://links.lww.com/CURRUROL/A5 (levels 1 and 2), with the risk factors categorized in level 1 as having higher priority. Results of the evaluation of this model,

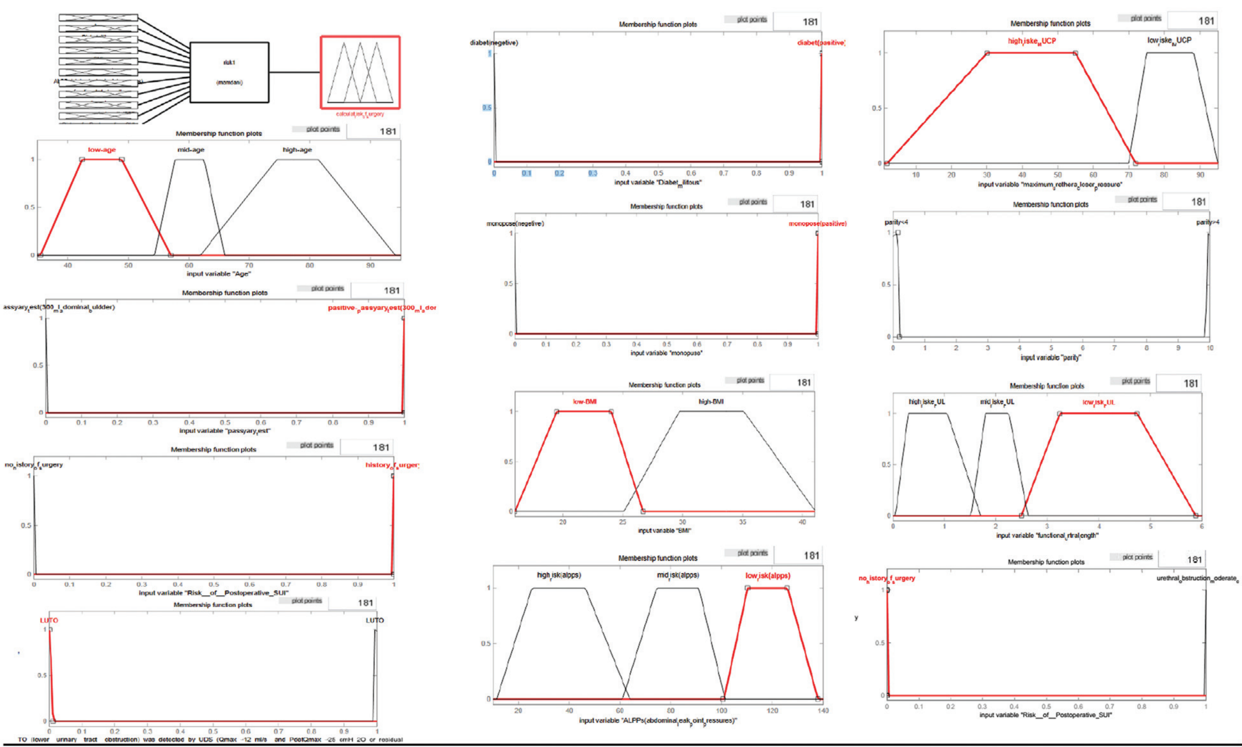

Figure 2. Membership function plot.

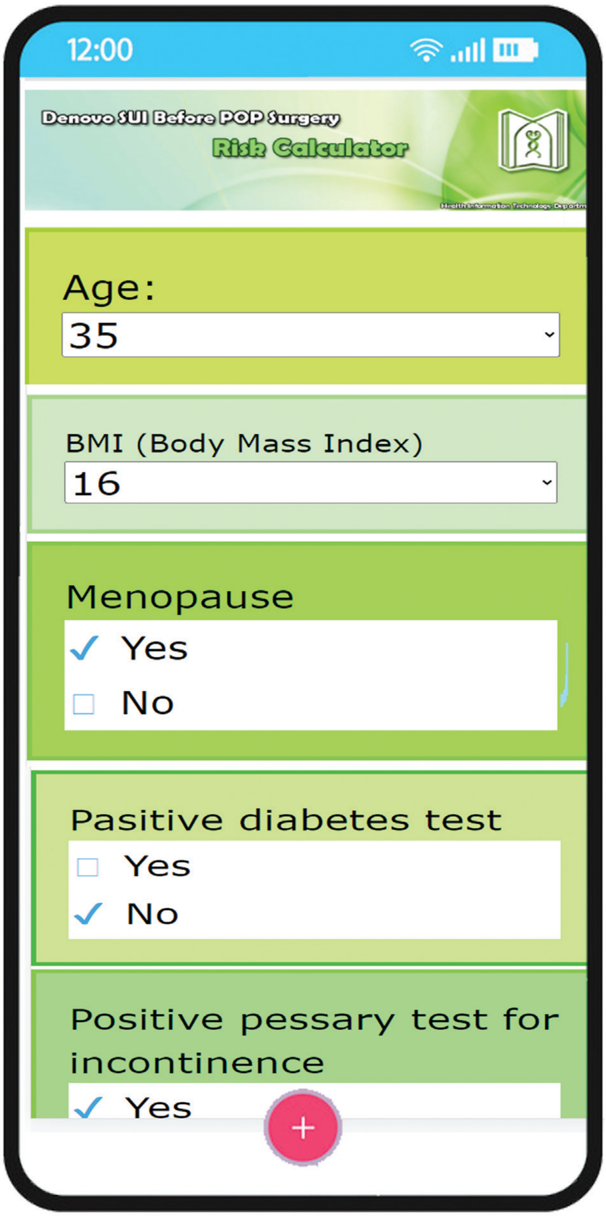

Figure 3. User interface.

performed retrospectively using blind comparison of medical records with system recommendations, as shown in Table 1, demonstrated that 90% of results matched. The overall accuracy of the system was 93.33%, with a sensitivity of 96.29% and specificity of 66.66%.

4. Discussion

Decision-making regarding prognosis, diagnosis, and the presence or absence of conditions, such as the risk of de novo SUI after POP surgery, are very complex for surgeons. Therefore, determining which characteristics are associated with de novo SUI occurrence is of utmost importance. Fuzzy logic-based expert systems can be very useful in solving such problems. The high incidence of de novo SUI after POP surgery in women, with an almost 50% probability, has major ramifications for patients far beyond that of other postoperative complications, which are much less prevalent.[32] Patients must often wait at least 6 months postoperatively to be assessed for de novo SUI, significantly delaying the answer as to whether prophylactic surgery should be performed at the same time of prolapse surgery.[2]

Although there are numerous urodynamic tests used for the assessment of urinary incontinence risk, they confer only a 17%–39% predictive value for clinicians attempting to clarify a diagnosis before surgery.[2,33,34] Experts, however, are more optimistic about the results of diagnostic tests than those of urodynamic ones.[34,35] Risk prediction DSS models could help improve decision-making by specialists and also reduce costs for patients. So far, successful DSSs such as fuzzy logic-based systems for the prediction of mortality and survival of patients after cardiac surgery,[36] prediction of heart disease risk,[19] a fuzzy expert system for the diagnosis of coronary artery disease,[37] a risk prediction system for breast cancer,[38] and prediction of the pathological stage of prostate cancer[39] have been introduced. In this study, 12 factors were used for risk calculation modeling (including age, BMI, diabetes, pessary test, history of surgery, urethral obstruction [moderate or more severe], and parity, along with urodynamic variables including abdominal leak point pressures, functional urethral length, maximum urethral closure pressure and lower urinary tract obstruction) in order to create a more comprehensive model for physicians than those used in a previous model[2] which merely included 6 factors (age, BMI, parity, diabetes, pessary test, and urine leakage associated with a feeling of urgency). The previous model did not rely upon urodynamic testing variables, despite the fact that such test results could have a significant role in detecting and predicting SUI.[40,41] In a model used to predict urinary incontinence risk described by Jelovsek et al., an online calculator had been designed for women undergoing POP surgery that had predicted incontinence risk using statistical and regression models. The results of that study demonstrated that the model was more accurate than stress testing (area under the curve = 0.72 vs. 0.54, $p < 0.001$).[2] Multivariate regression was also utilized in their computational model, and its performance had been evaluated with 1000 samples. Seven predictors had been correspondingly considered for this model, acquired from 2 clinical trials. A study by Dutta et al., to predict risks of cancer, found that fuzzy rules outperformed other classical methods.[42]

Some of the risk factors identified in this study, such as age and BMI, were given higher priority than others.[17,27,43,44] The inclusion of other risk factors, such as menopause, was controversial because it had not been cited as a risk factor in 1 study[45] but was mentioned as an important risk factor in others.[46] Therefore, in our model, the prediction of risk for a given patient cannot be solely based upon the presence or absence of a highly-rated risk factor. Moreover, our model used trapezoidal membership functions based on fuzzy logic, which are effective in distributing variable intervals and ultimately calculating confidence intervals more accurately, consequently making calculations in a more precise and easier manner as compared to regression and statistical methods. Empiric evaluation of the results of the calculator using our fuzzy expert system, based upon retrospective medical records data, should thus be considered an important strength of this study. According to the results described above, the accuracy of our calculator was more than 90%, which compares favorably with a 87% accuracy level of the model proposed by Jelovsek et al.[3]

Among the limitations of this study was the absence of a clear gold standard, although there have been various standards cited in previous studies or expert opinions in this field. Furthermore,

Table 1

Evaluation of fuzzy logic system accuracy.

Case record	Risk prediction (system) (based upon levels 1 and 2 risk factors)	Risk prediction (Physician)	Accordance
1	Low risk	Low risk	✓
2	Low risk	Low risk	✓
3	Low risk	Low risk	✓
4	Low risk	Low risk	✓
5	Low risk	Low risk	✓
6	Low risk	Low risk	✓
7	Low risk	Low risk	✓
8	Low risk	Low risk	✓
9	Low risk	Low risk	✓
10	Low risk	Low risk	✓
11	Low risk	Medium risk	X
12	Low risk	Low risk	✓
13	Low risk	Low risk	✓
14	Low risk	Low risk	✓
15	Low risk	Low risk	✓
16	Low risk	Low risk	✓
17	Low risk	Low risk	✓
18	Low risk	Low risk	✓
19	Medium risk	Low risk	X
20	Low risk	Low risk	✓
21	Medium risk	Medium risk	✓
22	Low risk	Low risk	✓
23	Low risk	Low risk	✓
24	Low risk	Low risk	✓
25	Low risk	Low risk	✓
26	Low risk	Low risk	✓
27	Medium risk	Medium risk	✓
28	Low risk	Low risk	✓
29	Low risk	Low risk	✓
30	Low risk	Low risk	✓

this model is only suitable for women with no primary SUI symptoms who have already undergone surgery. So, this model may not be applicable to women currently experiencing SUI symptoms. It does, however, show potential for improving decision-making by specialists in terms of management of patients undergoing surgery by providing expert guidance for the physician making clinical decisions. Additionally, this web-based calculator and its other mobile application versions provide an accessible and easy-to-use tool for physicians. In the future, more intelligent and precise models may be achieved through the use of artificial intelligence-based techniques such as machine learning and deep learning, especially as more data become available. Comparing different methods can provide additional evidence for obtaining the most accurate and optimal results.

5. Conclusion

In this study, a fuzzy logic-based clinical DSS in the form of an online calculator was designed to calculate predictors of de novo SUI after POP surgery in women who had been affected by surgeons' decisions to perform or not to perform preventive surgery. This online calculator was thus designed in 2 web-based and mobile application formats in order to enhance convenience in helping surgeons make point-of-care decisions. This system demonstrated a high degree of certainty when compared to retrospective medical record data, with an accuracy, sensitivity, and specificity of the final system of 93.33%, 96.29%, and 66.66%, respectively. With further study, if applied into clinical practice, this system could assist surgeons in predicting the risk of a de novo SUI diagnosis and the need for preventive surgery, thereby improving clinical outcomes. In the future, it is hoped that by incorporating larger laboratory and clinical data sets, we can create a more comprehensive knowledge base that could be used for other intelligent methods such as data mining and deep learning, which in turn could lead to more accurate prediction model for de novo SUI. Application of the fuzzy expert system to include larger populations so that results could be more broadly generalized should also be studied in future research.

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None.

Statement of ethics

The research presented and reported in this paper was conducted within the guidelines for research ethics outlined by the Iran National Committee for Ethics in Biomedical Research (Approval ID: IR.TBZMED.REC.1398.200). According to the National Ethical Committee guideline, all participants provided written informed consent at enrolment. All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflicts of interest statement

No conflict of interest has been declared by the author.

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Author contributions

Seyyde Yalda Moosavi: Data collection and analysis, design, software development, and drafting the manuscript;
Sakineh Hajebrahimi: Data collection and analysis, clinical supervision, and revising the manuscript;
Taha Samad-Soltani: Data collection and analysis, project administration, and revising the manuscript.

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