RESEARCH

Development of an artificial intelligence system to estimate postoperative discomfort after impacted third molar surgery

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ABSTRACT

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Background: Artificial Neural Network (ANN) is relatively crude electronic model based on the neural structure of human brain which was used in the field of medicine in different purposes. It can be used for many medical branches especially for estimating the course of a certain disorder or treatment procedure. The aim of this study is to use ANN in maxillofacial surgery to estimate the postoperative symptoms after third molar surgery.

Methods: The pre and post-operative information of 175 consecutive patients who needed extraction of impacted third molar teeth were employed to train an ANN. After the training process, the information of 26 cases was used in order to verify the network's ability to predict the post-operative symptoms such as swelling, pain, decrease of mouth opening, bleeding, number of days to return to normal activities and duration of activity restriction. The results obtained from ANN were compared with the results of patients self-reported information. The correlation between the postoperative symptoms of the patients and outcomes obtained from the ANN were analyzed statistically.

Results: Close association was found between the patients' reports and ANN results on post-operative pain, swelling, bleeding, number of days to return to normal activities and duration of activity restriction.

Conclusion: The proposed ANN approach is easy to implement and adapted to predict the response of the postoperative outcomes. The model can be further extended to include more variables and experimental data to increase reliability.

KEYWORDS

Activity restriction, artificial neural network, postoperative discomfort, third molar surgery

ÖZ

Gömülü üçüncü molar cerrahisinden sonra postoperatif rahatsızlığı tahmin etmek için yapay zeka sisteminin geliştirilmesi

Amaç: Yapay Sinir Ağı (YSA), tıp alanında farklı amaçlar için kullanılan nispeten insan beyninin sinir yapısına dayanan ham elektronik modeldir. Özellikle belirli bir hastalığın seyrini veya tedavi prosedürünü tahmin etmek için birçok tıp dalında kullanılabilmektedir. Bu çalışmanın amacı, üçüncü molar cerrahisinden sonra postoperatif semptomları tahmin etmek için maksillofasiyal cerrahide YSA kullanmaktır.

Gereç ve Yöntemler: Gömülü üçüncü molar dişleri çekilmesi gereken ardışık 175 hastanın ameliyat öncesi ve sonrası bilgileri bir YSA'yı eğitmek için kullanıldı. Eğitim sürecinin ardından; şişme, ağrı, ağız açıklığında azalma, kanama, normal aktiviteye dönme gün sayısı ve aktivite kısıtlama süresi gibi postoperatif semptomları öngörme yeteneğini doğrulamak için 26 vakanın bilgileri kullanılmıştır. YSA'dan elde edilen sonuçlar, hastaların kendi rapor ettiği bilgilerin sonuçlarıyla karşılaştırıldı. Postoperatif hastaların semptomları ile YSA'dan elde edilen sonuçlar arasındaki korelasyon istatistiksel olarak analiz edildi.

Bulgular: Ameliyat sonrası ağrı, şişme, kanama, normal aktivitelere dönme gün sayısı ve aktivite kısıtlama süresi üzerine hastaların raporları ile YSA sonuçları arasında yakın ilişki bulundu.

Sonuç: Önerilen YSA yaklaşımının, ameliyat sonrası sonuçların yanıtını öngörmek için uygulanması kolay ve uygulanabilirdir. Model, güvenilirliği artırmak için daha fazla değişken ve deneysel veri içerecek şekilde genişletilebilir.

ANAHTAR KELİMELER

Aktivite kısıtlaması, yapay sinir ağı, postoperatif rahatsızlık, üçünci molar cerrahisi

The surgical removal of impacted third molars is the most frequently performed procedure in oral and maxillofacial surgery and is usually produces pain, facial swelling and trismus postoperatively. Additionally, infection, dry socket, trigeminal nerve injuries and mandible fractures could also be seen as rare complications.[1,2] Morbidity risk increases with increasing age, position and location of the tooth, and duration of the surgical procedure. It is very important to inform the patient about post-operative

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period as well as the risks and benefits of the procedure. Clinicians should clearly identify risk factors that may lead to post-operative discomfort and inform patients about the duration of activity restriction and incapacity to work after the surgery. The estimation of the duration of return to normal activity and work is generally made based on the patient and operation related factors.

Artificial neural network (ANN) is a highly robust multifactorial mathematic model, imitating human brain structure and function, that has been applied successfully in the prediction, classification, function estimation, and pattern recognition and completion problems in many disciplines, including medicine.[3] ANN is a branch of artificial intelligence and it was first used in the field of maxillofacial surgery by Brickley and Shepherd[4] who developed and tested 12 neural networks of different architectures to make lower third molar treatment planning decisions. They reported high sensitivity and specificity when compared with the decisions of a senior oral surgeon. They suggested that the neural network could play a useful role in supporting dental practitioners making third molar referral decisions. ANN could also be a useful tool to estimate the patients' quality of life during the post-operative period.

In the present study, we have created an ANN model for prediction of postoperative symptoms of patients after impacted third molar surgery. According to the outcomes of the ANN model, we have aimed to assess the patient's incapacity to work owing to postoperative discomfort and estimate the accuracy of the model.

MATERIALS AND METHODS

Study design

The study was approved by the Ethical Committee on Human Research of Ondokuz Mayıs University, Samsun, Turkey (2012/521). All patients were informed before they included to the study and signed a written consent form. 175 consecutive patients who needed extraction of impacted third molar teeth between January and December 2015 were included to the study. All included patients had partially or completely impacted third molar teeth, covered by mucosa and the roots were fully formed in all cases. Patients who had a serious medical disorder or bleeding dyscrasia that may affect the healing period excluded from the study. A standardized surgical procedure performed by four surgeons, who had at least three years maxillofacial training at the same center. Each patient had standardized wisdom tooth surgery, under similar conditions.

Demographic data (age, gender, tobacco and alcohol use), presence of systemic disease, localization (maxilla or mandible), impaction level, retention and position (Winter classification) of the tooth, periodontal position (Winter classification) of the tooth, periodontal status and any disease related with the tooth such as pericoronitis were evaluated and noted preoperatively. Duration of the surgical procedure (minute), the need for suturing, postoperative antibiotics and anti-inflammatory administration noted as operation-related information. Written discharge instructions are given to all patients. Usual postoperative instructions were given to patients. All patients received a self-reported questionnaire including; pain level (assessed with a 10-point visual analogue scale anchored by the verbal descriptors "no pain" and "very severe pain"), swelling grade, measurement of mouth opening, postoperative bleeding, number of day to return to normal activities and duration of restricted function. The patients were told to assess their symptoms day by day and record it on the survey for five days beginning from the operation night. The surveys were collected 7 days after the operation when patients visited the clinic for suture removal.

The pre- and intra-operative informations and post-operative questionere results of the patients were employed for training an ANN. After creation of the neural network, 26 random samples were selected randomly from the patients' database. The correlation between the real data obtained from the patients' self-reported survey and ANN results about post-operative symptoms were evaluated.

Decision-making algorithm

The basic structure of ANN consists of input, hidden, and output layer. Input and output layers are the data that the researcher obtains from experiments and/or observations. The input data can be preprocessed such as normalization, scaling, or windowing to achieve the best training performance. There are 17 inputs and 6 outputs in the proposed ANN structure. The inputs and their associated levels are as below:

Parameters	Normalization
Age	15-30 (1), 30-45 (2), 45-55 (3), 55 and above (4)
Gender	Female (1), male (2)
Smoking	Yes (1), no (2)
Alcohol	Yes (1), no (2)
Systemic Disease	Yes (1), no (2)
Localization	Maxilla (1), mandible (2)
Impaction	Semi (1), full (2)
Retention of the tooth	Mucosa (1), bone (2)
Position of the tooth	Vertical (1), mesioangular (2), distoangular (3), horizontal (4)
Periodontal Tissue Status	None (1), gingivitis (2), periodontitis (3)
Pericoronitis Story	Yes (1), no (2)
Operation Time	Minute
Complication	Yes (1), no (2)
Suturation	Primary (1), secondary (2)
Postoperative Antibiotics	Yes (1), no (2)
Postoperative Anti-inflammatory drugs	Yes (1), no (2)
Anti-inflammatory Mouthwash	Yes (1), no (2)
Postoperative Pain	VAS (0 – 10)
Postoperative Swelling	No (0), light (1), medium (2), severe (3)
Postoperative Bleeding	Yes (1), no (2)
Postoperative Decrease in Mouth Opening	Yes (1), no (2)
Postoperative Incapacity to work	Number of days
Activity Limitation	Number of days

The hidden and output layers consist of activation neurons whose activation functions may be selected freely. The number of hidden layer neurons can be chosen using the Eq. (1).

$$Number\_of\_neurons = \sqrt{2n+1} \quad (1)$$

Where *n* is the number of input neurons. It can also be determined using trial and error procedure and the key point is to get minimum training error and maximum performance. It has been reported that using too many layers and neurons in hidden layer affects the performance of ANN negatively. The performance is simply defined as a minimum squared error (MSE). Therefore, it is simply a starting point before the training procedure. Another point that affects the performance of ANN is the selection of training algorithm. There are three training algorithms commonly used in literature, i.e. Bayesian Regularization, Levenberg-Marquardt, and Scaled Conjugate Gradient.

In this work, these algorithms were tested according to number of neurons, MSE for training, MSE for testing, and MSE for all to define the best performance (Table 1).

Table 1.

Testing of training algorithms

Training algorithms	Number of neuron	MSE for training	MSE for testing	MSE for all
Bayesian Regularization	8	0.89508	0.34615	0.86594
Bayesian Regularization	10	0.90713	0.82672	0.89482
Bayesian Regularization	12	0.9199	0.62684	0.8977
Bayesian Regularization	14	0.92848	0.64941	0.90407
Bayesian Regularization	16	0.93921	0.65997	0.90636
Levenberg-Marquardt	8	0.73469	0.82373	0.73598
Levenberg-Marquardt	10	0.82563	0.83178	0.82008
Levenberg-Marquardt	12	0.77669	0.75084	0.77157
Levenberg-Marquardt	14	0.83139	0.69286	0.79873
Levenberg-Marquardt	16	0.85541	0.71142	0.83892
Scaled Conjugate Gradient	8	0.75673	0.59893	0.7469
Scaled Conjugate Gradient	10	0.73426	0.73105	0.7345
Scaled Conjugate Gradient	12	0.74269	0.6075	0.72568
Scaled Conjugate Gradient	14	0.7279	0.7354	0.72045
Scaled Conjugate Gradient	16	0.75659	0.79582	0.7539

According to the pre-testing results, the best training algorithm is chosen as Bayesian Regularization with 10 neurons in the hidden layer. Table 1 simply describes and helps the researchers to get the best network type with the maximum testing performance. Figure 1 shows the structure of the suggested ANN of this study.

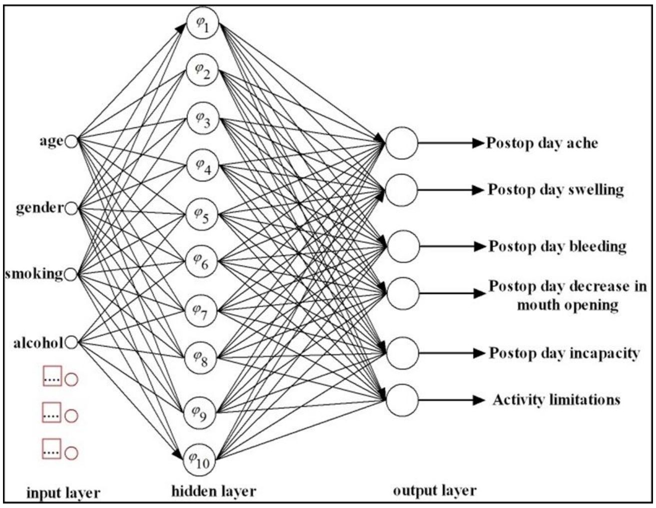

Figure 1.

The suggested ANN structure

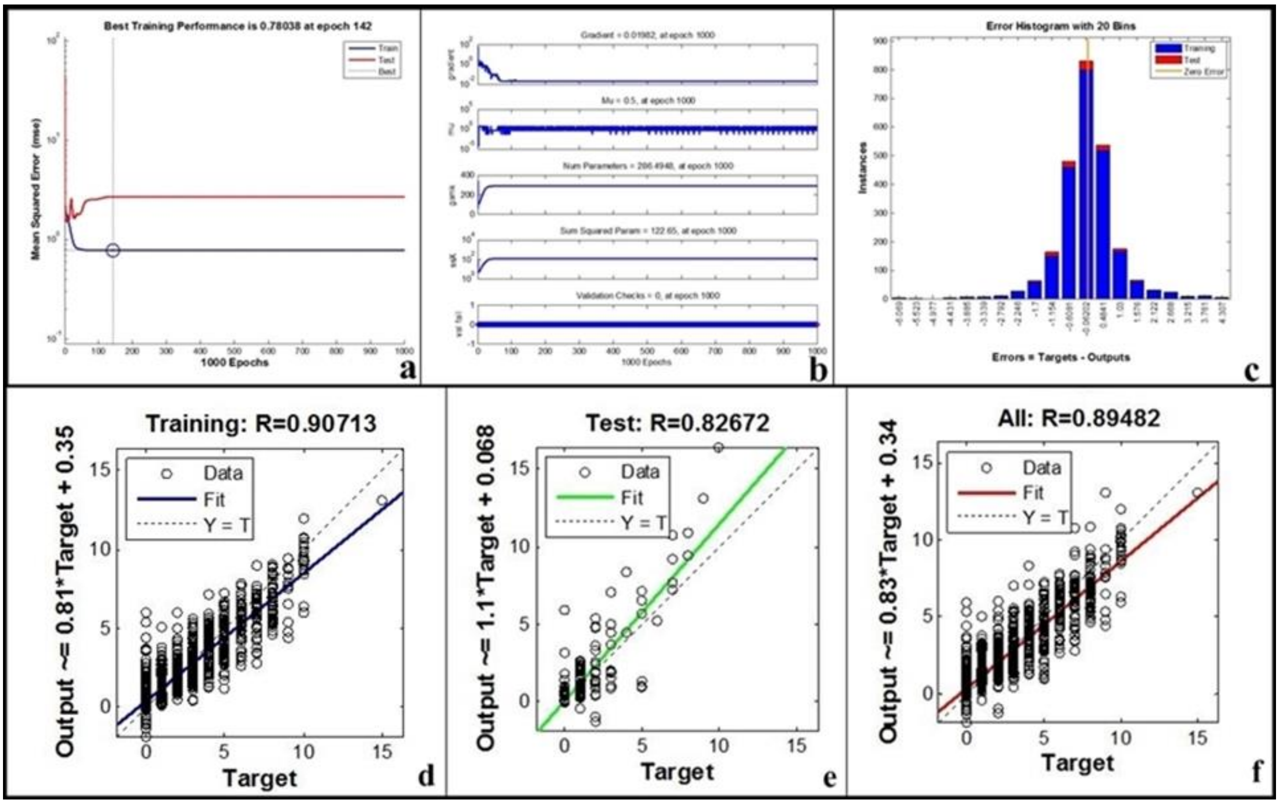

Figure 2.

(a) The best training performance, **(b)** Statistical data for the suggested network
(c) Histogram representation of the errors, **(d, e, f)** The regression results of the proposed ANN structure

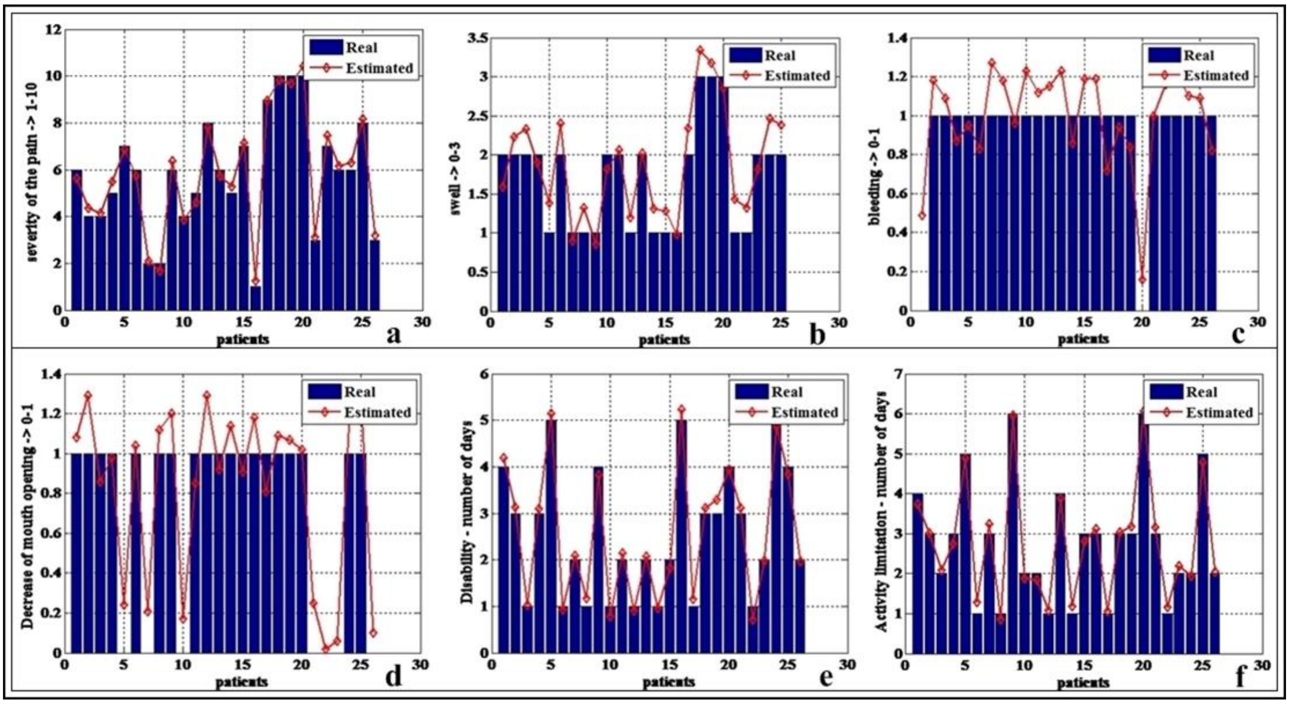

Figure 3.

The results cover the first day of post-operative outcomes. **a)** Real and estimated values of post-operative pain, **b)** Real and estimated values of postoperative swelling, **c)** Real and estimated values of post-operative bleeding, **d)** Real and estimated values of postoperative decrease in mouth opening, **e)** Real and estimated values of post-operation incapacity, **f)** Real and estimated values of activity limitation

The input layer consists of 17 neurons; the hidden layer consists of 10 neurons while the output layer has 6 neurons. Using Eq. (1) the number of hidden neurons can be calculated as 6 but 10 neurons in hidden layer present the best performance for this work. The letter ***w*** represents the weights and ***b*** represent biases (Figure 1).

The epoch number was selected as 1000 for the calculations and the following Figure 2a, Figure 2b, and Figure 2c demonstrate the performance plots.

The best training performance was calculated as 78% at the epoch of 142 (Figure 2a). Figure 2b shows the statistical data for the network under analysis. Similarly, the histogram graphs of the associated errors can be seen in Figure 2c. The error is the difference between targets and network outputs. Figure 2c shows the regression results of the analyzed network for training, testing, and overall performance.

Figure 2d, Figure 2e and Figure 2f show the regression results of the analyzed network for training, testing, and overall performance. As seen in Figure 2d, Figure 2e and Figure 2f, the determination coefficient (R) are calculated as 90.71 %, 82.67 %, and 89.48 % for training, testing, and overall performances, respectively. The performances can easily be increased by employing more input data. The total available data is the number of 175 and 15 % of it has been used for the testing procedure.

Statistical analysis

IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA) was used for the data analysis. Point be-serial correlation coefficient was computed to assess the relationships between the variables obtained from patient self-reported surveys and ANN.

RESULTS

The study sample consisted of 175 subjects. Female patients comprised 66.7 %. Tobacco use was reported among 20 % of patients, and 16.7 % reported alcohol use. Most subjects (94.4%) had no systemic disease. The mean duration of operation was 12.47 minutes (4.30±5.9). The mean duration of postoperative disability (i.e., number of days that subjects were unable to perform normal daily activities) and restricted activity was 2.28 and 2.26 days, respectively. Post-operative swelling, pain and decrease in mouth opening at the 6 days-period were documented for the subjects, at Table 2.

26-patient's samples were selected randomly from the patient database to test the correlation between the patients' self-reported scale and ANN. The correlation between the post-operative pain, swelling, bleeding and symptoms of the patients and outcomes obtained from the ANN were analyzed statistically and the close association was found (Table 3). The results cover the first day of postoperative outcomes were presented in Figure 3. The following Figure 3e and Figure 3f demonstrate the real and estimated post-operative disability and activity limitation, respectively.

Table 2.

Post-operative swelling, pain and decrease in mouth opening at the 6-days period

	Grade of swelling	1 day	2 day	3day	4 day	5 day	6day
Swelling(%)	0(none)	8,9	12,2	16,7	34,4	48,9	56,7
	1(slight)	30	33,3	48,9	45,6	43,3	38,9
	2(moderate)	46,7	34,4	24,4	17,8	5,6	2,2
	3(severe)	12,2	17,8	7,8	0	0	0
Pain (median)		5,46	3,7	3,04	2,06	1,3	1,01
Decrease in mouth opening(%)	0(none)	28,9	36,7	40	53,3	68,9	76,7
	1(slight)	67,8	60	57,8	44,4	27,8	21,1
	2(moderate)	1,1	1,1	0	0	0	0

Table 3.

Close correlation was found between the patients' self-reported symptoms and outcomes obtained from the artificial neural network (p<0,001)

	Average Real	Estimated	Standard Deviation Real	Estimated	Correlation
Pain	5.5769	5.6288	2.7448	2.7113	0.9949
Swelling	1.72	1.8692	0.6782	0.6879	0.9354
Bleeding	0.9231	0.2717	0.9935	0.2548	0.7724
Decrease in mouth opening	0.7308	0.8219	0.4523	0.4376	0.9504
Number of day to return to normal activities	2.5769	2.5969	2.1387	2.1474	0.9974
Duration of restricted function	2.8846	2.8946	2.9028	2.8675	0.9985

DISCUSSION

A certain amount of pain, swelling and trismus is expected after third molar surgery; however, more serious complications could also be seen in relation to surgical difficulty and individual problems.[5-12] Pain is the most common symptom seen after third molar surgery. It reaches its maximum intensity at 3–5 hours and generally continues for 2–3 days postoperatively.[13] Facial swelling and trismus will reach their characteristic maximum levels 48 to 72 hours after surgery and influenced by local tissue destruction and the severity of the surgical procedure.[14] Patients generally want to know how long are they going to experience discomfort and how long these symptoms cause restriction for their daily activities and work. It is generally difficult to estimate the course of postoperative symptoms. Toward that end, this study was designed to estimate the severity of postoperative symptoms such as swelling, pain, decrease of mouth opening, bleeding, number of days to return to normal activities and duration of activity restriction by using a computer-based program. In this study, patients' preoperative data and self-reported post-operative symptoms were used to create an ANN model that could predict postoperative symptoms after third molar surgery. The limitation of this study is that the ANN was created according to patients self-reported variables. The patients were told to assess their symptoms day by day and record it on the survey. Post-operative pain, swelling and decrease of mouth opening, restriction of doing daily routine activity and function limitation were noted by the patients, themselves. In our opinion, the expected error could be decreased by increasing the patient population that was used for training the ANN structure. There is no doubt that the more patients are used, the more accurate results could be obtained.

Artificial Neural Networks have been a very handy tool to simulate the relation between the inputs and outputs. ANN consists of a series of solution procedures of different variables such as connections, biases, and weights. These variables can mostly be defined as random and updated during the solution process to get the minimum training and testing error. There are many ANN structures proposed by several researchers but among them, multi-layer back propagation (MLP) is regarded as the most popular one and can be seen in many studies which cover engineering, medical, and even some social research works.[15,16] In this study, an ANN structure with 17 inputs, 10 neurons in a hidden layer and an output layer with 14 neurons is proposed. Many training algorithms are tested according to their MSE values to achieve the best performance of ANN testing system. In this study, we developed an ANN to predict the postoperative symptoms, activity limitation and restriction of doing daily routine activity and beginning to work after third molar surgery. The best training performance is calculated as 78% at the epoch of 142. A close association was found between the patients' self-reported post-operative symptoms and the symptoms that were predicted by ANN. The proposed ANN-based diagnostic system is easy to use and developed in Visual Basic 6.00, and can be a useful method for surgeons for giving information to the patient about the post-operative symptoms before the surgery. Further research including the advanced network models that use both clinical and imaging data is recommended.

According to the authors' knowledge, this is the first ANN model created to estimate the post-operative outcomes after third molar surgery. The potential practical implications of this model are, to provide information for patients about the post-operative period, predicting the need for hospitalization after the operation, estimating the proper medication use. More accurate predictions can be achieved if the model is trained with larger patient group. One of the advantage of the network is new data can be added to improve the model over time. ANN models are useful tools for medicine and it can help the clinicians in many ways if they incorporated into clinical workflow.

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