Obesity Surgery (2019) 29:2276–2286
https://doi.org/10.1007/s11695-019-03849-w

ORIGINAL CONTRIBUTIONS

A Clinical Decision Support System for Predicting the Early Complications of One-Anastomosis Gastric Bypass Surgery

Abbas Sheikhtaheri[1] · Azam Orooji[2] · Abdolreza Pazouki[3] · Maryam Beitollahi[4,5]

Published online: 26 April 2019

Abstract

Background/Objective One of the most effective treatments for patients with obesity, albeit with some complications, is obesity surgery. The aim of this study was to develop a clinical decision support system (CDSS) to predict the early complications of one-anastomosis gastric bypass (OAGB) surgery.

Subjects/Methods This study was conducted in Tehran, Iran on patients who underwent OAGB surgery in 2011–2014 in five hospitals. Initially, variables affecting the OAGB early complications were identified using the literature review. Patients' data were extracted from an existing database of obesity surgery. Then, different artificial neural networks (ANNs) (multilayer perceptron (MLP) network) were developed and evaluated for prediction of 10-day, 1-month, and 3-month complications.

Results Factors including age, BMI, smoking status, intra-operative complications, comorbidities, laboratory tests, sonography results, and endoscopy results were considered important factors for predicting early complications of OAGB. A CDSS was developed with these variables. The accuracy, specificity, and sensitivity of the 10-day prediction system in the test data were 98.4%, 98.6%, and 98.3%, respectively. These figures for 1-month system were 96%, 93%, and 98.4% and for the 3-month system were 89.3%, 86.6%, and 91.5%, respectively.

Conclusions Using the CDSS designed, we could accurately predict the early complications of OAGB surgery.

Keywords Obesity surgery · One-anastomosis gastric bypass · Early complications · Clinical decision support system · Machine learning · Data mining · Artificial neural network

Introduction

Obesity is a major health problem worldwide [1]. According to the World Health Organization (WHO), in 2016, about 2 billion people were at least overweight worldwide [2]. Obesity may result in physical and psychological problems as well as social and economic burdens, ischemic heart disease, hypertension, type 2 diabetes, increased vulnerability to cancers,

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11695-019-03849-w) contains supplementary material, which is available to authorized users.

✉ Abbas Sheikhtaheri
sheikhtaheri.a@iums.ac.ir

Azam Orooji
orooji_9898@yahoo.com

Abdolreza Pazouki
apazouki@yahoo.com

Maryam Beitollahi
mb.dazzlingstar2012@gmail.com

[1] Health Management and Economics Research Center, Department of Health Information Management, School of Health Management and Information Sciences, Iran University of Medical Sciences, Tehran, Iran

[2] Department of Health Information Management, School of Health Management and Information Sciences, Iran University of Medical Sciences, Tehran, Iran

[3] Minimally Invasive Surgery Research Center, Iran University of Medical Sciences, Tehran, Iran

[4] Minimally Invasive Surgery Research Center, Iran University of Medical Sciences, Tehran, Iran

[5] Department of Health Information Management, School of Health Management and Information Sciences, Iran University of Medical Sciences, Tehran, Iran

and a wide range of other diseases [3]. It is proved that dietary treatments are not very effective for treatment of obesity in the long run [4]. Nowadays, a variety of surgical techniques have been developed and are considered the first choice for treating obesity [5].

Different types of obesity surgery methods are used to treat this condition including sleeve gastrectomy (SG), laparoscopic adjustable gastric band (LAGB), duodenal switch, gastric bypass (GB), and biliopancreatic diversion [4]. Gastric bypass is performed with a variety of techniques, with one-anastomosis gastric bypass (OAGB) being among the most popular approaches [6]. In this technique, a very small portion of the stomach is first separated and then, the small intestine is anastomosed to the stomach about two meters after the Treitz ligament [7]. Concerning its popularity, it has been shown that the number of OAGB has considerably increased [2]. However, OAGB has various early complications such as bleeding and hematoma [8], pulmonary embolism (PE), wound infection, biliary reflux, leakage, and malnutrition [9]. The early complication rate is about 3.4% among patients [8].

A variety of different factors such as gender, age, and comorbidities may contribute to the occurrence of the early post-surgery complications which should be considered before the surgery [10]. Indeed, decisions about the surgery should be made taking these factors into account [11]. Timely and accurate diagnosis or prediction of these complications is difficult. However, prediction of complications before the surgery may reduce them significantly after operation [12].

There are few studies regarding prediction of post-surgery complications in patients with obesity. Chiappetta et al. developed a tool, Edmonton obesity staging system (EOSS), for classifying patients with obesity into five grades and four degrees based on their clinical, mental, and functional characteristics [13]. In another study, Janik et al. developed a statistical prediction model and calculator for hemorrhagic complications after laparoscopic sleeve gastrectomy (LSG). They concluded that this model could help in surgical decision-making, choosing the best surgeons, and predicting hemorrhagic complications after LSG [14]. In another study, Gupta et al. developed a calculator for bariatric surgery morbidity risk and concluded that predicting complications before surgery using this system may result in fewer complications, as well as greater patients' and physicians' satisfaction [15]. Furthermore, Coblijn et al. evaluated an obesity surgery mortality risk score for the prediction of post-operative complications after primary and revisional laparoscopic Roux-en-Y gastric bypass. They found a significant relationship between re-operation and development of severe complications and mortality [16].

Clinical decision support systems (CDSS) are computerized programs that use machine-learning algorithms, artificial intelligence (AI), risk models, or other methods to help physicians make accurate and appropriate decisions. These systems may also be used to predict complications of a disease [17–19]. In spite of the abovementioned well-developed risk and prediction models in the field of obesity, to the best of our knowledge, there are no reported risk models or CDSS to predict the early complications of OAGB. Therefore, our aim is to develop and evaluate a novel CDSS based on machine learning and AI techniques to predict the early complications of this surgery at 10 days, one month, and three months post-operation.

Materials and Methods

Study Design and Settings

This cross-sectional study was retrospectively performed in Tehran, Iran on patients with obesity undergoing OAGB in five hospitals including Rasoul-e-Akram, Mohebe Yas Kosar, Farmanieh, Bahman, and Milad. These hospitals varied in terms of educational and governmental status. This study was conducted in two phases. In the first phase, for identifying the influential factors, we conducted a literature review and expert survey. Then, in the second phase, we collected data about these factors, developed the CDSS, and evaluated the system.

Definition of Early Complications

We defined complications as any conditions or symptoms occurring after OAGB resulting in re-admission or identified in the follow-up visits after surgery. These complications included gut perforation, liver injury, bleeding, splenic injury, major vessel injury, leak, obstruction, wound infection, intra-abdominal abscess, and PE. Because of the limited number of each complication in our database, we defined a complicated patient as a patient who has at least one of these complications at 10-day, 1-month, or 3-month follow-up visits separately.

Variable Identification

To identify the most important variables, we first searched Pubmed, Scopus, and Google Scholar (Supplementary Table S1 and Fig. S1). Our inclusion criteria were the articles published in Persian or English in 2010–2017, the articles with available full text, and those focusing on the OAGB early complications. The articles related to other bariatric surgery methods, letters to editors, and non-peer reviewed papers were excluded. Then, the variables affecting the early complications of OAGB were extracted from the final selected articles.

To select the most important factors, we first considered the most cited ones. Then, we developed a questionnaire including questions about the importance of each factor. The questionnaire was sent to all 26 obesity surgeons in Tehran. They were asked to rank each factor based on a five-point Likert scale. Factors with at least 70% agreement among the surgeons were finally selected for analysis.

Patient Selection and Data Collection

We extracted the data from the database of the National Obesity Surgery Registry. The abovementioned five hospitals are participants of this registry. This registry records the pre-surgery, intra-operative, and post-surgery data. We extracted data of patients who had these following inclusion criteria: (1) an OAGB surgery from 2011 to 2014 in the mentioned hospitals, (2) one-year post-surgery follow-up visits, and (3) the patients whose complications were diagnosed by their physicians (not those recorded via phone call follow-up visits). Finally, 1509 records were extracted; however, patients with missing data about complications were excluded.

Data Pre-processing

We first developed some models on the original data; however, because of some errors in data, the performance of the models was not appropriate. Therefore, in order to achieve the best models, we conducted some well-defined pre-processing techniques.

Imputing Missing Values

Imputing missing variables is a well-documented method to improve the accuracy of machine learning algorithms. To this end, there are many methods such as replacing the mode, mean, or mean of a group [18, 20]. In this study, for the variables, there was no significant relationship between two classes (complicated and non-complicated patients), and as such the missing values were replaced with the category having the highest frequency (categorical data) or mean (numerical data). However, if there was a significant difference, we replaced the missing values with the mean of each class for numeric values and the frequency of each class for non-numeric values [20]. We excluded the surgery duration and Vit D3 and did not impute the missing values of these factors because of the many missing values.

Data Balancing

Our database was imbalanced in terms of the frequency of records in each class. Therefore, in order to balance the data, the synthetic minority over-sampling technique (SMOTE) was employed. This method adds some artificial data to the previous data [21]. After using software R version 3.2.3 for data balancing, the data for 10-day network reached 2970, while for 1-month and 3-month networks, they amounted to 5877.

Model Development

One of the AI algorithms which can be used to develop CDSS systems is artificial neural networks (ANNs). These networks are inspired by natural neural networks and process the input data via neural processing units in a parallel way [22]. It has been proved that ANN is a suitable technique for data modeling as their accuracy and precision are greater than those of traditional statistical methods and other machine learning algorithms. In addition, many CDSSs have been successfully developed using these networks in medicine [18, 23]. ANNs have many different types [24], out of which we selected the multilayer perceptron (MLP) networks as our training algorithm since they usually outperform other techniques on healthcare data [18, 25–27].

We built different ANNs to predict the occurrence of complications at 10-day, 1-month, and 3-month periods post operation. The collected data were randomly divided into test (15%), validation (15%), and training (70%) datasets. The test data was used for evaluation, the validation data for validating the model, and the training data for training the networks. Varieties of networks were developed based on different topologies via trial and error, and finally, the most appropriate networks were selected for developing the CDSS.

Statistical Analysis

We used the Statistical Package for the Social Sciences (SPSS) software version 20 in order to analyze the data. Univariate analyses were performed by the independent sample t test and chi-square. We considered the P value ≤ 0.05 as significant.

Evaluation of Model Performance and Developing the CDSS

We evaluated our networks' performance by the cross-entropy error, confusion matrix, accuracy, specificity, and sensitivity. Furthermore, we utilized the receiver operating characteristic (ROC) curve and the area under curve (AUC). Maximization of AUC indicates a better model. All evaluation metrics were calculated using standard methods [20, 28]. Finally, we developed a graphical user interface (GUI) so that bariatric surgeons can use the system. All of the models and the GUI were developed and evaluated using the MATLAB software (version R 2013a).

Ethical Considerations

The protocol of this study was reviewed and approved by the ethics committee of Iran University of Medical Sciences, Tehran, Iran (Code: IR.IUMS.REC 1395.9311304002).

Results

The Included and Excluded Variables

We reviewed 26 articles [6, 9, 10, 15, 16, 29–49] to identify the factors that may result in OAGB complications (Table 1). Twenty surgeons participated in our survey (response rate = 76.9%). Among them, 60% were aged 45 years or older and 50% had more than 10 years of working experience.

According to the survey results, the most important factors were age, weight, BMI, bilio-pancreatic obstruction, duration of surgery, smoking status, malnutrition, open surgery, obesity, intra-operative complications (gastrointestinal perforation, splenic injury, liver injury, major vessel injury, bleeding, death, and other events), comorbidities (cardiovascular disease, pseudotumor cerebri (PTC), psychological problems, CVA, sleep apnea, and deep-vein thrombosis (DVT)), laboratory tests (hemoglobin (Hb), hematocrit (HCT), platelet count (PLT), ferritin, FBS, HbA1C, Choles, ALB, Vit B12, and Vit D3), sonography (cholelithiasis and fatty liver), and endoscopy (hiatal hernia, ulcer, helicobacter, polyps, esophagitis, and columnar epithelium).

The weight was not included in the models due to their inclusion in the BMI formula. In addition, surgery method was not included as the numbers of laparoscopic method ($N = 1491$) and open surgery ($N = 2$) were not balanced. Vit D3 and surgery duration was also excluded in the models because of the many missing values. We developed and tested different models based on different sets of these input variables and finally selected the set of variables with the best performance.

The Patients' Descriptive Data

The mean age, height, weight, and BMI of patients was 38.70 years, 164 cm, 124.38 kg, and 46.04 kg/m2, respectively. Additionally, the mean duration of surgery was 70.13 min. Mortality was nihil. Most patients were non-smokers (81%) and did not have any intra-operative complications (97.6%) or comorbidities (59.4%). Gastrointestinal perforation (0.7%) and psychiatric problems (31.5%) were the most common intra-operative complications and comorbidities, respectively. Sonography of the most patients was abnormal (84.4%). Additionally, most patients had at least one abnormality in their endoscopy (67.9%). Other descriptive data are presented in the supplementary tables (Tables S2 and S3).

At 10-day, 1-month, and 3-month periods, the majority of patients did not suffer from any symptoms of vomiting, diarrhea, constipation, dumping syndrome, smelly stool, gastroesophageal reflux, inappropriate connection of arteries and veins, cholelithiasis, dry skin, hair loss, and wound infection. Additionally, no patient suffered from protein deficiency and incisional hernia. At 10-day and 1-month periods, the most frequent complications were constipation and hair loss, respectively (Table 2).

The Comparison Between Two Groups

Univariate analysis showed that there were no significant differences in age, BMI, hemoglobin (Hb), HCT, ferritin, FBS, albumin, and Vit B12 in complicated and non-complicated patients at 10-day, 1-month, and 3-month follow-up visits. Smokers had significantly more post-surgery complications at 1-month follow-up visits. Patients with higher PLT had more post-surgery complications at 10-day (P value = 0.001), 1-month, and 3-month follow-up visits (P value < 0001). Furthermore, patients with ulcer (P value = 0.001) and helicobacter (P value = 0.05) had more post-surgery complications at 10 days after surgery. At 1-month follow-up visits, patients with no psychiatric problems had fewer complications (P value = 0.025). There were no other significant differences between the two groups of patients in terms of other variables.

The Networks and Their Evaluation

The 10-Day MLP Network

Different sets of variables were selected as inputs and finally, the network with 32 variables (features) including age, BMI, smoking status, intra-operative complications (gastrointestinal perforation, splenic injury, liver injury, major vessel injury, bleeding, and other events), comorbidities (cardiovascular disease, PTC, psychological problems, CVA, sleep apnea, and DVT), laboratory tests (Hb, HCT, PLT, ferritin, FBS, HbA1C, Choles, ALB, and Vit B12), sonography results (cholelithiasis and fatty liver), and endoscopy results (hiatal hernia, ulcer, helicobacter, polyps, esophagitis, and columnar epithelium) had the best performance among other networks developed to predict 10-day complications. The best performance of this network was found in the validation data in Epoch 84 (0.03993). In addition, the AUC for this network was equal to 0.996. Figure 1 demonstrates the ROC curve in test data. Based on the confusion matrix, the accuracy, specificity, and sensitivity of this network in test data were 98.4%, 98.6%, and 98.3%, respectively. Other results are presented in the Table 3.

Table 1 Risk factors identified by literature review

Number	Risk factors	References
1	Comorbidities	[9, 10, 16, 33, 34, 36, 41, 43, 45, 47, 49, 50]
2	Intra-operative complications	[6, 39, 44, 49]
3	Body mass index	[9, 15, 16, 45]
4	Age	[6, 10, 16, 33]
5	Gender	[10, 16, 33]
6	Surgery duration	[32–34]
7	Weight	[9, 33]
8	Open surgery	[44, 49]
9	Laboratory tests and their results	[10, 34]
10	Surgery difficulty	[34, 36]
11	The patient immobility	[32, 33]
12	Bilio-pancreatic obstruction	[29]
13	Smoking	[4]
14	Large intestine hole	[49]
15	Malabsorption	[35]
16	Shortness of the biliopancreatic limb	[41]
17	Obesity	[45]
18	Endoscopy results	[10]
19	Long length of the Jejunum	[46]
20	Inflammation	[48]
21	History of cancer	[10]
22	Surgeon's skill and experience	[30]
23	Tissue manipulation	[45]
24	Early postoperative ambulation	[39]
25	Malnutrition	[49]
26	More anastomosis	[36]
27	The lack of HCL in stomach	[34]
28	Menstrual disorders	[34]
29	Non-alcoholic liver disease	[34]
30	Vegetarianism	[34]
31	Menstrual disorders	[34]
32	Diabetic nephropathy	[34]
33	Port-site incarceration of the small bowel	[31]
34	Traumatic injury to the afferent loop	[31]

The 1-Month MLP Network

The input variables for the 1-month network were exactly the same as those of the 10-day network where the output variable was 1-month early complications. The best performance of this network was found in the validation data in Epoch 168 (0.021275). In addition, the AUC for the selected network was equal to 0.995. Figure 2 displays the ROC in the test data. For 1-month MLP network, the accuracy, specificity, and sensitivity in the test data were 96%, 93%, and 98.4%, respectively (Table 3).

The 3-Month MLP Network

The input variables for the 3-month network were exactly the same as those of the 10-day and 1-month networks, with the output variable being 3-month early complications. The best performance of the 3-month early complication

Table 2 Distribution of the post-surgery complications among patients before pre-processing

Post-surgery complications		Follow-up		
Vomiting		10-day	1-month	3-month
	Yes	16 (1.1)	67 (4.4)	76 (5.0)
	No	1421(94.2)	1358 (90.0)	1256 (83.2)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Diarrhea	Yes	43 (2.8)	83 (5.5)	75 (5.0)
	No	1394(92.4)	1342 (88.9)	1257 (83.3)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Constipation	Yes	98 (6.5)	231 (15.3)	90 (6.0)
	No	1339(88.7)	1194 (79.1)	1242 (82.3)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Dumping syndrome	Yes	1 (0.1)	12 (0.8)	13 (0.9)
	No	1436(95.2)	1413 (93.6)	1319 (87.4)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Smelly stool	Yes	47 (3.1)	124 (8.2)	221 (14.6)
	No	1390(92.1)	1301 (86.2)	1111 (73.6)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Dilatation of esophagus	Yes	0 (0)	0 (0)	0 (0)
	No	1437(95.2)	1425 (94.4)	1332 (88.3)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Gastroesophageal reflux disease (GERD)	Yes	0 (0)	3 (0.2)	2 (0.1)
	No	1437(95.2)	1422 (94.2)	1330 (88.1)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Stomach ulcer	Yes	1 (0.1)	1 (0.1)	1 (0.1)
	No	1436(95.2)	1424 (94.4)	1331 (88.2)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Anastomotic stricture	Yes	0 (0)	1 (0.1)	1 (0.1)
	No	1437(95.2)	1424 (94.4)	1331 (88.2)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Incisional hernia	Yes	0 (0)	0 (0)	0 (0)
	No	1437(95.2)	1425 (94.4)	1332 (88.3)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Cholelithiasis	Yes	0 (0)	0 (0)	2 (0.1)
	No	1437(95.2)	1425 (94.4)	1330 (88.1)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Dry skin	Yes	18 (1.2)	175 (11.6)	223 (14.8)
	No	1419(94.2)	1250 (82.8)	1109 (73.5)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Hair loss	Yes	10 (0.7)	105 (7.0)	438 (29.0)
	No	1427(94.6)	1320 (87.5)	894 (59.2)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Wound infection	Yes	2 (0.1)	0 (0)	3 (0.2)
	No	1435(95.1)	1425 (94.4)	1329 (88.1)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Protein deficiency	Yes	0 (0)	0 (0)	0 (0)
	No	1437(95.2)	1425 (94.4)	
	Missing	72 (4.8)	84 (5.6)	177 (11.7)
Total frequency*	Yes	198 (13.1)	559 (37.0)	653 (43.3)
	No	1239(82.1)	865 (57.3)	679 (45.0)
	Missing	72 (4.8)	84 (5.6)	177 (11.7)

*At least one complication during 10-day, 1-month, or 3-month period. In addition, the numbers in the paranthesis show the percentage

network was found in the validation data in Epoch 225 (0.04922). Furthermore, the AUC for the selected 3-month MLP network was equal to 0.931. Figure 3 reveals the ROC in test data. For 3-month MLP network, the accuracy, specificity, and sensitivity were 89.3%, 86.6%, and 91.5%, respectively (Table 3).

Graphical User Interface of the System

We built a GUI for physicians to use the system for predicting the OAGB complications. This program consists of seven input sections including personal variables, smoking status, intra-operative complications, comorbidities, laboratory tests,

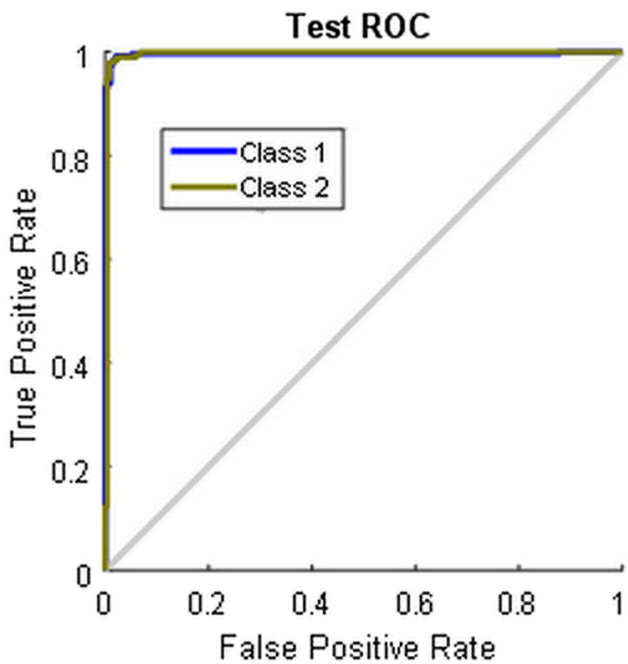

Fig. 1 The ROC curve of the 10-day complication prediction model in test data

sonography, and endoscopy results, and an output section consisting of OAGB early complications. Users can enter the variables listed as inputs, and then receive the outputs in terms of three-period early complications of OAGB surgery (Fig. 4).

Discussion

Initially, we identified several important factors for developing the networks and finally selected 32 features for modeling the occurrence of complications. For example, several studies emphasized age as an effective factor in the occurrence of OAGB complications [6, 10, 16, 33]. The risk of morbidity and mortality is higher in people aged 45 years old or over [16]. Additionally, patients with a BMI ≥ 50 are considered at a higher risk of developing post-surgery complications [9, 15, 16, 45]. Although these factors are important, we did not see any difference between the two groups with and without complications; nonetheless, we included them in our prediction system.

We considered comorbidities such as cardiovascular disease, PTC, psychological problems, CVA, sleep apnea, and DVT in our networks. Previous studies have shown that comorbidities may result in the onset of post-operative complications after OAGB [9, 16, 33, 34, 36, 41, 43, 45, 47, 49, 50]. Specifically, DVT [33, 45, 47], sleep apnea [9, 33, 47, 49], CVA [10], PTC [49], psychiatric problems [41], and cardiovascular disease [45, 47] are among the most effective factors. Ignoring any of these diseases before surgery can lead to complications after the surgery [9, 45].

Paying attention to the results of the laboratory tests before surgery is important [10, 34]. Typically, the results of the closest test to the surgery time are the most important thing to consider. We found that patients with higher PLT had more post-surgery complications in all follow-up periods. Based on our analysis, we finally included laboratory tests such as HBA1C, Hb, FBS, HCT, PLT, Alb, VitB12, ferritin, and choles before the surgery in our CDSS. Meanwhile, smoking is considered a major contributor to the complications of OAGB surgery [9, 45, 51]. For example, smokers may have problems with post-surgery wound healing [51]. In addition, in our study, there was a significant relationship between smoking status and post-surgery complications. Specifically, smokers had significantly more post-surgery complications at 10-day and 1-month follow-up visits.

Intra-operative complications are recognized as a very effective factor for post-operative OAGB complications. According to some studies, intra-operative complications including gastrointestinal perforation, splenic injury, liver injury, major vessel injury, bleeding, and other events are the causes of post-operative complications [6, 35, 44, 49]. Nevertheless, we did not find any significant relationship between intra-operative and post-surgery complications.

Table 3 Evaluation results of the final selected networks

	10-day network			1-month network			3-month network		
	Train data	Test data	Validation data	Train data	Test data	Validation data	Train data	Test data	Validation data
Sensitivity	99.4	98.3	100	98.5	98.4	99	95.5	91.5	92.2
Specificity	97.4	98.6	95.4	95.2	93	95.7	88.8	86.6	89.4
Accuracy	98.5	98.4	97.8	97.1	96	97.5	92.5	89.3	90.9

All numbers are in percent

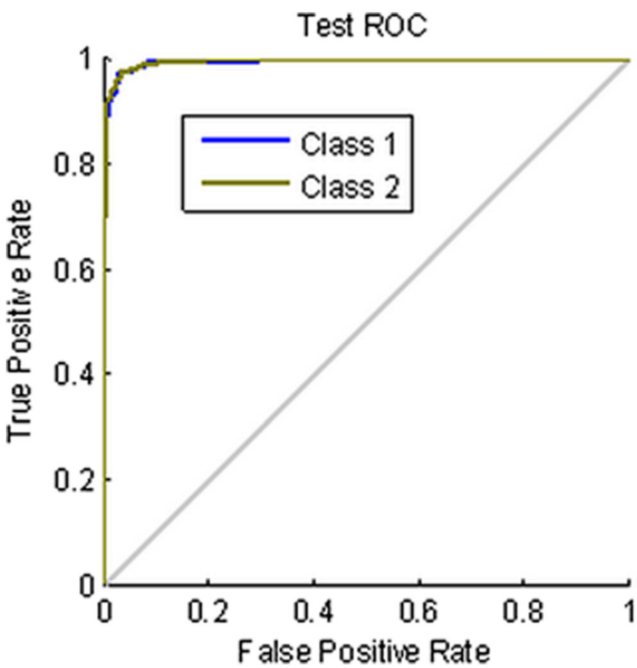

Fig. 2 The ROC curve of the 1-month complication prediction model in test data

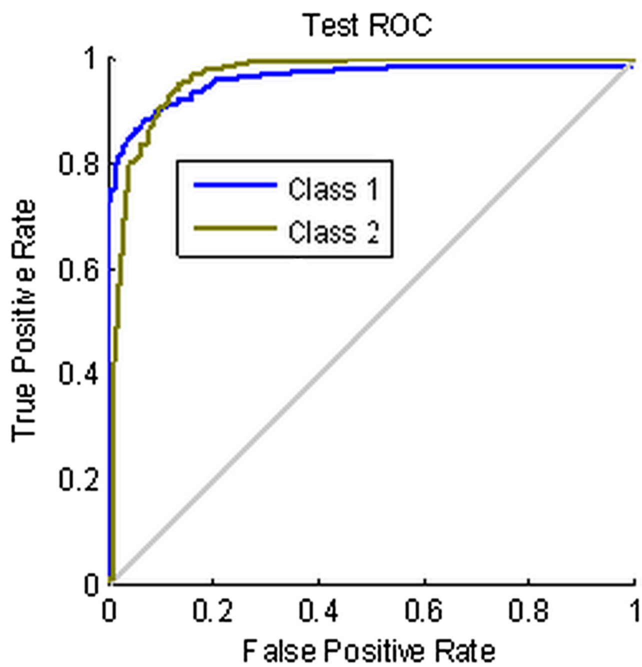

Fig. 3 The ROC curve of the 3-month complication prediction model in test data

Only 30 patients (2%) had some types of intra-operative complications. Among them, a limited number of patients had post-operative complications. All these indicate the reason why we did not find this association. However, we included intra-operative complications in our CDSS because of their importance.

Predicting post-surgery complications by considering all of the abovementioned factors is difficult. However, the system developed in this study can predict the early complications with the accuracy of 98.4% in the test data of the 10-day MLP network, 96% in the one-month network, and 89.3% in the 3-month network. There are previous studies on classification of patients with obesity, prediction of post-surgical death and complications, success rate in weight loss, and surgery in patients [13, 14, 16, 44]. However, none of them focused on prediction of early complications of OAGB surgery.

Using this practical system, surgeons can easily input the required data into the system and receive the results for 10-day, 1-month, and 3-month prediction, separately. If this CDSS is used correctly, it may have many benefits for patients including reducing post-operative early complications, preventing re-operations and re-admission of patients, saving patients' time and money, and increasing patient safety. Furthermore, it may also be beneficial to identify and prioritize patients with obesity prior to the surgery thereby screening the patients with more critical conditions more quickly and accurately and operating them faster accordingly. This system may also result in improved physicians' decision-making process, ensuring the precision and the accuracy of the decisions made, saving the physicians' time, reducing their workload, and generally improving their performance [13, 14, 16].

Study Limitations and Future Studies

The results of this study should be interpreted considering some limitations. First, the system was not implemented and evaluated in a real situation. Indeed, our evaluation was retrospective. Therefore, future studies should focus on implementation of this system and evaluation of its impact on patients' outcomes prospectively.

Second, we only had access to the data of surgeons with high surgical skills (more than 10 years experience) and the data of surgeons with less experience were not included in our data modeling. Therefore, we could not include any data about surgeons' experience in our model. In future, consideration of more data from a variety of surgeons and including the surgeons' skill in data modeling may be beneficial.

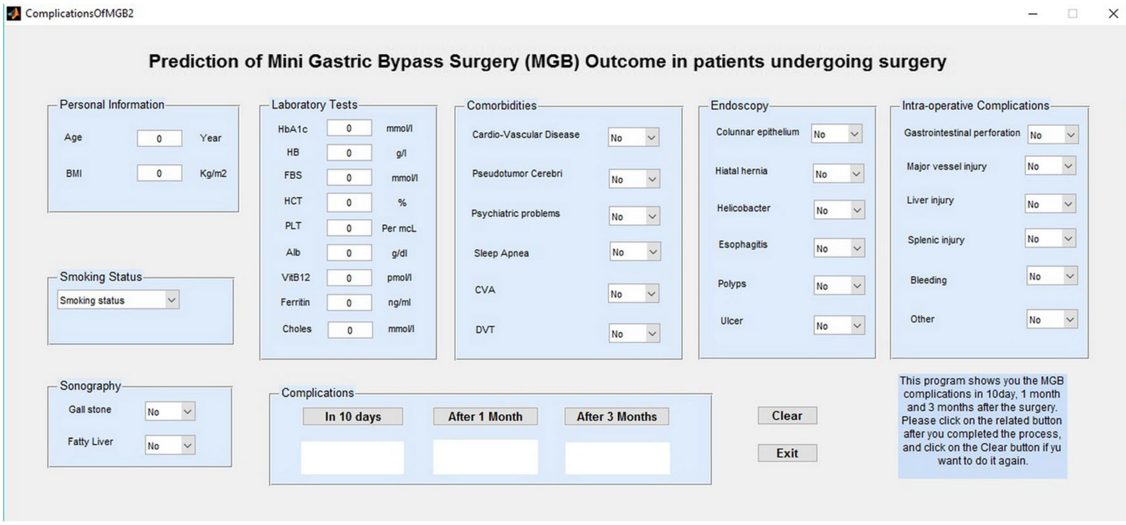

Fig. 4 The graphical user interface of CDSS for prediction of the OAGB early complication

Further, our data were not balanced in the two groups of patients; therefore, we balanced it via producing artificial data using SMOTE technique. We compared the results of networks we developed with the original (imbalanced) data with the selected networks and found that the SMOTE technique enhanced the performance of networks. Although this method is a well-defined technique in machine learning [21], we recommend that the study should be replicated with a data set which is more balanced.

Also, some studies have indicated that longer duration of the procedure may have a correlation with postoperative complications [32–34]. The reason is that it may increase the need for anesthetic substance as well as the incidence of pulmonary complications including PE and DVT, pneumonia, and respiratory failure [32]. However, because of high missing values, we did not include this variable in our model. Including this variable in future studies may improve our results.

In addition, we could not predict complications individually, and we just considered total complications. It is suggested that a larger data set should be used in future studies in order to predict every single complication. Further, we just used MLP technique for data modeling. Although, various studies conducted on the comparison between the MLP and other methods suggest that the MLP networks far outperform other methods in prediction, classification, and detection [26, 27], further studies using other techniques are recommended. Eventually, our system is not available online for physician use at the time of this publication. Developing a web-based system based on our results is recommended. Additionally, developing CDSS for predicting 1-year post-surgery OAGB complications and predicting complications of other obesity operations are also suggested.

Conclusion

Thirty-two variables including age, BMI, smoking status, intra-operative complications (gastrointestinal perforation, splenic injury, liver injury, major vessel injury, bleeding, and other events), comorbidities (cardiovascular disease, PTC, psychological problems, CVA, sleep apnea, and DVT), laboratory tests (Hb, HCT, PLT, ferritin, FBS, HbA1C, choles, ALB, and Vit B12), sonography results (cholelithiasis and fatty liver), and endoscopy results (hiatal hernia, ulcer, helicobacter, polyps, esophagitis, and columnar epithelium) were considered important factors for predicting early complications of OAGB. The CDSS developed in this study has a good performance and may predict the early complications of OAGB surgery. It may help surgeons make decisions on how to manage the surgery process.

Acknowledgements This study is supported by Iran University of Medical Sciences, Tehran, Iran (IUMS/SHMIS-1395.9311304002). Additionally, we appreciate National Obesity Surgery Registry to provide data for this study.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict(s) of interest.

Informed Consent For this type of study, formal consent is not required.

Ethical Approval The protocol of this study was reviewed and approved by the ethics committee of Iran University of Medical Sciences, Tehran, Iran (Code: IR.IUMS.REC 1395.9311304002). All procedures performed in this study were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Financial Support This study did not receive any financial support.

References

1. Jafari-Adli S, Jouyandeh Z, Qorbani M, et al. Prevalence of obesity and overweight in adults and children in Iran; a systematic review. J Diabetes Metab Disord. 2014;13(1):121.
2. Chaim EA, Ramos AC, Cazzo E. Mini-gastric bypass: description of the technique and preliminary results. ABCD Arquivos Brasileiros de Cirurgia Digestiva (São Paulo). 2017;30(4):264–6.
3. Khurram M, Paracha SJ, Hamama-tul-Bushra Khar ZH. Obesity related complications in 100 obese subjects and their age matched controls. J Pak Med Assoc. 2006;56(50)
4. Buchwald H, Avidor Y, Braunwald E, et al. Bariatric surgery: a systematic review and meta-analysis. JAMA. 2004;292(14):1724–37.
5. Fazel I. Surgical treatment of morbid obesity. Iran J Surg. 2011;19(2):1–21.
6. Georgiadou D, Sergentanis TN, Nixon A, et al. Efficacy and safety of laparoscopic mini gastric bypass. A systematic review. Surg Obes Relat Dis. 2014;10(5):984–91.
7. Rutledge R. The mini-gastric bypass: experience with the first 1, 274 cases. Obes Surg. 2001;11(3):276–80.
8. Park HJ, Hong SS, Hwang J, et al. Mini-gastric bypass to control morbid obesity and diabetes mellitus: what radiologists need to know. Korean J Radiol. 2015;16(2):325–33.
9. Genser L, Carandina S, Tabbara M, et al. Presentation and surgical management of leaks after mini–gastric bypass for morbid obesity. Surg Obes Relat Dis. 2016;12(2):305–12.
10. Abraham A, Ikramuddin S, Jahansouz C, et al. Trends in bariatric surgery: procedure selection, revisional surgeries, and readmissions. Obes Surg. 2016;26(7):1371–7.
11. Arterburn DE, Courcoulas AP. Bariatric surgery for obesity and metabolic conditions in adults. BMJ. 2014;349:3961.
12. Lee CW, Kelly JJ, Wassef WY. Complications of bariatric surgery. Curr Opin Gastroenterol. 2007;23(6):636–43.
13. Chiappetta S, Stier C, Squillante S, et al. The importance of the Edmonton obesity staging system in predicting postoperative outcome and 30-day mortality after metabolic surgery. Surg Obes Relat Dis. 2016;12(10):1847–55.
14. Janik MR, Walędziak M, Brągoszewski J, et al. Prediction model for hemorrhagic complications after laparoscopic sleeve gastrectomy: development of sleeve bleed calculator. Obes Surg. 2017;27(4):968–72.
15. Gupta PK, Franck C, Miller WJ, et al. Development and validation of a bariatric surgery morbidity risk calculator using the prospective, multicenter NSQIP dataset. J Am Coll Surg. 2011;212(3):301–9.
16. Coblijn UK, Lagarde SM, de Raaff CA, et al. Evaluation of the obesity surgery mortality risk score for the prediction of postoperative complications after primary and revisional laparoscopic Roux-en-Y gastric bypass. Surg Obes Relat Dis. 2016;12(8):1504–12.
17. Omidian Z, Hadianfard A. The study of clinical decision support systems role in health care(1980-2010). Jundishapur J Health Res. 2011;2(3):1–13.
18. Paydar K, Kalhori SRN, Akbarian M, et al. A clinical decision support system for prediction of pregnancy outcome in pregnant women with systemic lupus erythematosus. Int J Med Inform. 2017;97:239–46.
19. Sadoughi F, Sheikhtaheri A. Applications of artificial intelligence in clinical decision making: opportunities and challenges. Health Information Management. 2011;8(19):440–5.
20. Han J, Pei J, Kamber M. Data mining: concepts and techniques: Elsevier; 2011.
21. Chawla NV, Bowyer KW, Hall LO, et al. SMOTE: synthetic minority over-sampling technique. J Artif Intell Res. 2002;16:321–57.
22. Pourshahriar H, Tabatabaiei KR, Khodapanahi MK, et al. Artificial neural networks: a model for prediction. Developmental Psychology (Journal of Iranian Psychologists). 2009;5(20):307–21.
23. Sheikhtaheri A, Sadoughi F, Dehaghi ZH. Developing and using expert systems and neural networks in medicine: a review on benefits and challenges. J Med Syst. 2014;38(9):110.
24. Rathore H. Mapping biological systems to network systems: Springer; 2016.
25. Bounds DG, Lloyd PJ, Mathew BG. A comparison of neural network and other pattern recognition approaches to the diagnosis of low back disorders. Neural Netw. 1990;3(5):583–91.
26. Li C, Zhi X, Ma J, et al. Performance comparison between logistic regression, decision trees, and multilayer perceptron in predicting peripheral neuropathy in type 2 diabetes mellitus. Chin Med J. 2012;125(5):851–7.
27. Raad A, Kalakech A, Ayache M. Breast cancer classification using neural network approach: MLP and RBF. Networks. 2012;7(8):9.
28. Zhu W, Zeng N, Wang N. Sensitivity, specificity, accuracy, associated confidence interval and ROC analysis with practical SAS implementations. NESUG proceedings: health care and life sciences, Baltimore, Maryland 2010:1–9.
29. Almulaifi AM, Ser KH, Lee WJ. Acute gastric remnant dilatation, a rare early complication of laparoscopic mini-gastric bypass. Asian J Endosc Surg. 2014;7(2):185–7.
30. Birkmeyer JD, Finks JF, O'Reilly A, et al. Surgical skill and complication rates after bariatric surgery. N Engl J Med. 2013;369(15):1434–42.
31. Bruzzi M, Voron T, Zinzindohoue F, et al. Revisional single-anastomosis gastric bypass for a failed restrictive procedure: 5-year results. Surg Obes Relat Dis. 2016;12(2):240–5.
32. Currò G, La Malfa G, Caizzone A, et al. Three-dimensional (3D) versus two-dimensional (2D) laparoscopic bariatric surgery: a single-surgeon prospective randomized comparative study. Obes Surg. 2015;25(11):2120–4.
33. Inabnet WB, Belle SH, Bessler M, et al. Comparison of 30-day outcomes after non-Lap Band primary and revisional bariatric surgical procedures from the longitudinal assessment of bariatric surgery study. Surg Obes Relat Dis. 2010;6(1):22–30.
34. Jammu GS, Sharma R. A 7-year clinical audit of 1107 cases comparing sleeve gastrectomy, Roux-En-Y gastric bypass, and mini-gastric bypass, to determine an effective and safe bariatric and metabolic procedure. Obes Surg. 2016;26(5):926–32.
35. Kansou G, Lechaux D, Delarue J, et al. Laparoscopic sleeve gastrectomy versus laparoscopic mini gastric bypass: one year outcomes. Int J Surg. 2016;33:18–22.
36. Lee W-J, Ser K-H, Lee Y-C, et al. Laparoscopic Roux-en-Y vs. mini-gastric bypass for the treatment of morbid obesity: a 10-year experience. Obes Surg. 2012;22(12):1827–34.

37. Mason ME, Jalagani H, Vinik AI. Metabolic complications of bariatric surgery: diagnosis and management issues. Gastroenterol Clin N Am. 2005;34(1):25–33.
38. Musella M, Susa A, Greco F, et al. The laparoscopic mini-gastric bypass: the Italian experience: outcomes from 974 consecutive cases in a multicenter review. Surg Endosc. 2014;28(1):156–63.
39. Noun R, Skaff J, Riachi E, et al. One thousand consecutive mini-gastric bypass: short- and long-term outcome. Obes Surg. 2012;22(5):697–703.
40. Padwal R, Klarenbach S, Wiebe N, et al. Bariatric surgery: a systematic review and network meta analysis of randomized trials. Obes Rev. 2011;12(8):602–21.
41. Parmar C, Mahawar K, Boyle M, et al. Mini gastric bypass: first report of 125 consecutive cases from United Kingdom. Clin Obes. 2016;6(1):61–7.
42. Piazza L, Di Stefano C, Ferrara F, et al. Revision of failed primary adjustable gastric banding to mini-gastric bypass: results in 48 consecutive patients. Updat Surg. 2015;67(4):433–7.
43. Salgado Jr W, De Queiroz Cunha F, Dos Santos JS, et al. Early identification of infectious complications in bariatric surgery by the determination of peritoneal and systemic cytokines. Obes Surg. 2009;19(7):867–72.
44. Stenberg E, Szabo E, Ågren G, et al. Early complications after laparoscopic gastric bypass surgery: results from the Scandinavian obesity surgery registry. Ann Surg. 2014;260(6):1040–7.
45. Tambasco D, D'ettorre M, Gentileschi S, et al. Postabdominoplasty wound dehiscence in bariatric patients: biliopancreatic diversion versus gastric bypass: a preliminary study. Ann Plast Surg. 2015;75(6):588–90.
46. Umemura A, Lee WJ, Sasaki A, et al. History and current status of bariatric and metabolic surgeries in East Asia. Asian J Endosc Surg. 2015;8(3):268–74.
47. Wrzesinski A, Correa JM, Fernandes TMB, et al. Complications requring hospital management after bariatric surgery. ABCD Arq Bras Cir Dig. 2015;28(Supl.1):3–6.
48. Yang P-J, Lee W-J, Tseng P-H, et al. Bariatric surgery decreased the serum level of an endotoxin-associated marker: lipopolysaccharide-binding protein. Surg Obes Relat Dis. 2014;10(6):1182–7.
49. Mahawar KK, Jennings N, Brown J, et al. "Mini" gastric bypass: systematic review of a controversial procedure. Obes Surg. 2013;23(11):1890–8.
50. Madah G, Shabahang H, Barband M, et al. Outcomes and complications of Roux-en-Y open gastric bypass in morbid obesity: a short report. Tehran Univ Med J. 2014;72(9):643–7.
51. Manassa EH, Hertl CH, Olbrisch R-R. Wound healing problems in smokers and nonsmokers after 132 abdominoplasties. Plast Reconstr Surg. 2003;111(6):2082–7.