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Research Article

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Predicting of Stroke Risk Based On Clinical Symptoms Using the Logistic Regression Method

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Abstract

Mathematical modeling is one of the feasible methods that can be used to solve real problems. Modeling can be done using a variety of methods, including statistical methods that can be used to predict a variety of events. Health is one of the most important areas of research in the world today. Among the various diseases in the health sector, this study concerns stroke which is the second leading cause of death and long-term human disability, that has led to doing this research. The main objective of this research is to design and to build a predictive model of stroke based on symptoms and clinical reports, whether or not stroke occurs in patients in the near future. Using logistic regression technology, the main pathogenic factors of stroke have been found and their incidence has been predicted. In this study, clinical information from 5411 patients was collected and, after applying the LR method, the predictive model was designed.

Keywords : Stroke Risk; Risk Factors; Prediction; Logistic Regression.

1 Introduction

For each event statistical and data mining methods can be applied to classify the parameters that affect it, to identify the pattern of events and, finally to predict the events based on the facts and information available [15, 19] . In statistical methods, the relationships of variables can be modeled according to assumptions (including the normal distribution of the data, and the uniformity of the variance of the errors) and constraints. In recent years, attention has been paid to statistical models to classify medical data relating to various diseases and their consequences [16]. Furuta et al. stressed that stroke is one of the most serious problems facing the medical community in Asia, Europe, and North America [8].

There are two main types of strokes [9] ischemic stroke and hemorrhagic stroke. When a blood vessel is blocked due to a clot in the brain, an ischemic stroke has occurred. The blood clot can

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be created out of the brain, and move to the brain. According to statistics from the World Health Organization (WHO), nine out of ten strokes are ischemic strokes [20]. When a blood vessel in the brain ruptures, a hemorrhagic stroke has occurred. The result of this type of stroke is heavy bleeding, and it is usually difficult to stop the bleeding.

Today, more than a third of strokes occur in developed countries. In developing or developed countries, according to WHO data, stroke is one of the leading causes of human life-threatening diseases, which in 2005 there were about 5.7 million deaths, equivalent to 87% of the total population deaths [9]. It should be noted that each year the rate of stroke has been increased significantly[14]. On the other hand, rapid increase in number of young adults who suffer a stroke is one of the main challenges of health communities around the world [15]. In a recent classification provided by the World Stroke Organization (WSO), Iran is highlighted as one of the countries that have seen a significant increase in the rate of stroke [7].

According to statistics obtained by the Iranian Scientific Association of Stroke (ISAS), stroke is the second leading cause of death and the first cause of long-term disability in the country. According to statistics published by ISAS, every 5 minutes a person faces a stroke, in other words, one hundred thousand people in Iran, every year, face this disorder. The age of stroke in Iran is ten years lower than in developed countries [7, 18].

Thus, given the importance and prevalence of stroke worldwide, access to models capable of accurately predicting patient survival in people is crucial. Predicting whether or not a disease will occur can provide valuable information to planners, physicians, and health authorities. One of the methods used for modeling is the prediction method based on statistical and data mining methods. The most important goal of statistical and data mining methods is to determine the effective and predictable variables and to find their relationship [10].

In this article, we examine the effective variables and their relationships for stroke and proposes a statistical model for stroke prediction using the logistic regression (LR) method. For this reason, the clinical information from 5411 stroke patients is collected by the Neurosciences Research Center of University of Tabriz Medical Sciences, and 22 risk factors were considered by consulting with neuro physicians. After running the LR model, the classification tables of the actual observation and prediction, the table of the effective risk factors, and the predictive model were obtained. Then a column chart, and a classification chart were drawn. The main advantage of the predictive model is that by using the results of diagnostic tests and the patient's medical history followed by physical examinations, it can be used to predict the incidence or non-incidence of strokes.

The framework of this study is as follows:

A brief description of the stroke research literature can be found in the second section. The third section describes the research methodology. The fourth section presents a case study with an interpretation of the statistical results. Finally, the conclusions section summarizes the findings and implications of this study. .

2 Literature Review

Several studies have been carried out to study the risk factors and their consequences on the occurrence of a stroke. To have an initial view of the studies carried out, some research carried out by scholars on the subject under discussion around the world are listed below.

Mauthe et al [12] assessed the discharge destination of stroke patients using a mathematical model with six elements (bath, bowel, toilet, social interaction, lower body dressing and diet) based on functional independence measure (FIM). The FIM model measured these six elements to predict discharge at home, in a rehabilitation center or in a retirement home. Finally, the actual exit position of the patient was compared to the predicted position of the model developed using FIM. Charlesworth et al [2] developed a model for the prediction of stroke after coronary artery bypass grafting (CABG) using the LR method. The statistical population for their study was 33,062 consecutive patients who had been isolated CABG in northern New England between 1992 and 2001. The results showed a correlation of 0.99 between observed and predicted strokes. Dronne et al [5] proposed a mathematical model to represent the long-term dynamics of membrane potentials, cell volumes and ionic concentrations in intracellular and extracellular spaces during a stroke and to study the influence of each ionic current on cell swelling. They climaid that this model can help explore new treatment strategies to reduce stroke damage. Jee et al [11] provided the stroke risk prediction model using COX plots in the Korean population. The study population included 47,233 stroke events occurring over 13 years in 1,223,740 Koreans. The results showed that the average risk of stroke over 10 years was 3.52% for men and 3.66% for women. Overall, the actual stroke rates were similar to the event rates predicted by the predictive model. Chien et al [3] developed the Chinese stroke risk prediction model based on Cox's multivariate model. The variables evaluated in this study were: age, sex, systolic blood pressure, diastolic blood pressure, family history of stroke, atrial fibrillation and diabetes. The obtained results showed that the age factor gained higher points than the other factors on the incidence of the stroke. McClean et al [13] presented stroke patient management and capacity design based on mathematical models and networks. They developed a mathematical modeling approach that calculates the optimal number of stroke patients who are dispatched by ambulance from an inpatient hospital to satellite hospitals that offer inpatient stroke services. Zhuo et al [21] provided a prediction model for stroke recurrence in Chinese adults using characteristics of retinal vasculature. They used a multivariate LR method to identify risk factors associated with ischemic stroke within one year after the first stroke. Farhoudi et al [9] studied the subtypes, risk factors and death rate in northwestern Iran through COX curve. Their study population was 5355 stroke patients with various risk factors. The results of the study showed that hypertension, diabetes and smoking are the most important reasons for the onset of stroke. Ebrahimi et al [7] studied the impact of opium addiction (OA) and ischemic stroke in Isfahan, Iran. In this study, 672 patients with ischemic stroke and 293 patients without cardiovascular diseases were compared. The results showed that in addition to OA, diabetes, hypertension, hyperlipidemia, and smoking also play a crucial role in the incidence of stroke. Furuta et al [8] studied secular trends in the incidence, risk factors and prognosis of transient ischemic attack (TIA) in a general Japanese population. They estimated the risk factors for TIA using a Cox proportional risk model and compared them in different genders with different ages. Markidan et al [15] studied the relationship between smoking and the risk of ischemic stroke in young men. They used LR method to calculate the odds ratio for ischemic stroke by comparing current and former smokers with non-smokers. The results showed that this ratio was 1.88 for the current smoking group compared to non-smokers. Zhaoxi et al [22] developed new logistic regression models for the diagnostic and prognostic assessment of ischemic stroke. In this study with various risk factors, the results showed that the risk factors for hypertension, smoking, family history of ischemic stroke, HDL and LDL play a key role in the occurrence of stroke. Overall, a limited number of risk factors have been investigated for stroke in each study [10, 14, 18]. This study assesses 23 risk factors, some selected factors were derived from the literature review and others were suggested by experienced physicians.

3 Methodology

Mathematical analysis and modeling are essential parts of the epidemiology of diseases. Mathematical models extracted from disease surveillance data can be a useful tool to evaluate the proposed hypothesis about the disease. The main objective of modeling is to determine the effective variables, the relationships between variables, and the prediction. The prediction of the value of a dependent variable using independent variables, based on a linear or nonlinear model, is called regres-

sion, and its different types are linear regression, logistic regression (LR), etc [16]. Linear regression was developed in the field of statistics and is being studied as a model to understand the relationship between input and output numerical variables. This method is one of the most important statistical and machine learning algorithms [1].
LR is a type of regression in which the predictor variables can be quantitative or qualitative, while the predictable variable must be qualitative and it must have two levels. The meaning of a two-level variable is whether it is a member of a group or not [16]. This method like linear regression is one of the most applicable machine learning and statistical prediction methods which is used in various fields, especially in healthcare. LR is similar to linear regression, however, the method of estimating the coefficients is not the same. In linear regression, squares root of errors is minimized, while in the LR, the probability that an event may occur is maximized. To examine the significance of the relationship the standard Fisher and T-tests are used in linear regression analysis, while in LR, Chi-2 and Wald tests are used. The LR model uses the Logit function as a link function, while its error follows a polynomial distribution. Given the type of variables used in this study, which is all binary, the LR model was used for modeling and prediction. The general form of the LR model is as follows [17]:

$$Logit(p) = Ln(\tfrac{p}{1-p}) = \beta_0 + \beta_1 x_{1,i} + \cdots + \beta_k x_{k,i}, \quad (i = 1, \cdots, N), \ (k = 1, \cdots, K) \tag{3.1}$$

Where the $p = Pr(y = 1)$.

$$p = Pr(y_i = 1 \mid \vec{x}_i, \vec{\beta}) = \frac{\mathbf{e}^{\beta_0+\beta_1 x_{1,i}+\cdots+\beta_k x_{k,i}}}{1+\mathbf{e}^{\beta_0+\beta_1 x_{1,i}+\cdots+\beta_k x_{k,i}}} = \frac{1}{1+\mathbf{e}^{-(\beta_0+\beta_1 x_{1,i}+\cdots+\beta_k x_{k,i})}} \tag{3.2}$$

Where $x_{k,i}$ represents the predictor variables. $\beta_1, \beta_2, \cdots, \beta_k$ are the model estimation coefficients for the independent variables and show the effect coefficient. The p value shows the risk of getting or not getting the disease.

4 Case Study

The term stroke was coined and introduced into medicine by William Cole [4] at the end of the 17th century. Physiologically, stroke is an acute, focal injury of the central nervous system (CNS) of vascular origin, contributing to local or systemic neurological damage. According to the WHO definition of stroke, stroke is a clinical syndrome characterized by rapidly developing clinical signs of focal or global disturbance of brain function, lasting more than 24 hours or leading to death, with no other apparent cause than that of vascular origin [8].
The main reason for choosing stroke for the case study for this research is that the age of stroke in Iran is lower than in other societies. According to doctors, about 30% of strokes occur in people under the age of 50. Strokes are more common among young people in Iran than in other communities due to various factors such as obesity, sedentary lifestyle, urban culture, and diet [18]. In the next subsections, the study population, the collected data and their types, the results of the application of the LR model, and their interpretation will be presented in detail.

4.1 Study Population

5411 stroke patients referred to Imam Reza and Razi hospitals in Tabriz, East Azarbaijan Province, Iran, from April 2015 to April 2016 constitute our study population. This data from Tabriz Stroke Registry has been established in 2014 [6]. Among **5411** stroke patients, **2891** equal to 53.40% of them are men, and **2520** equal to 46.57% of them are women. The minimum and maximum ages of onset of the disease in men are **5** and **105** years, respectively, and in women, they are **9** and **102** years, respectively. The average age of stroke in Tabriz province is **66.54** years for men and **58.86** years for women. In this study, the entire population was chosen and there was no gender segregation.

Table 1: List of Risk Factors

Name of Risk Factors	Symbol
Hypertension	R˙1
Diabetes Mellitus	R˙2
Ischemic Heart Disease	R˙3
Artificial Heart Valve	R˙4
Ischemic Heart Disease	R˙5
Atrial Fibrillation	R˙6
Congestive Heart Failure	R˙7
Myocardial Infarction	R˙8
Carotid Artery Stenosis	R˙9
Previous Cerebrovascular Accident	R˙10
Previous Transient Ischemic Attack	R˙11
Hyperlipidemia	R˙12
Vertebrobasilar Insufficiency	R˙13
Deep Vein Thrombosis	R˙14
Peripheral Vascular Disease	R˙15
Head and Neck Trauma	R˙16
Oral Contraceptive Consumption	R˙17
Smoking	R˙18
Other Kinds Of Exposure to Smoke	R˙19
Addiction	R˙20
Alcohol Consumption	R˙21
Snoring	R˙22

4.2 Data Collection

The present study is a diagnostic study that can predict the likelihood of whether a stroke occurs or not based on independent variables. Data collected from patients are both quantitative and qualitative. The dependent variable in this study is considered a Stroke. After a review of the literature and a consultation with neurologists, 22 clinical risk factors were selected. Table 1 presents 22 selected risk factors for this study. These factors are independent variables making it possible to predict the dependent variable (Stroke). The values of all independent variables are binary, i.e. if a patient had a risk factor, the value is equal to one and, in the absence of a risk factor, its value is zero.

4.3 Results

To fit the LR model, information from **5411** patients was analyzed using SPSS.23 software. The model was built using **22** clinical risk factors reported by patients, with the Enter algorithm, and critical area $\alpha = 0.05$. The results of the analysis are presented in Tables 2 to 4, ($N = 5411$ and $K = 22$).

Table 2 shows the classification table based on actual observations. According to Table 2,

Groups Type	Observed
Stroke	5091
Non- Stroke	320
Totall	5411

Table 2: The actual observations

5091 have had a stroke, and **320** did not have a stroke.
Table 3 provides the classification table of prediction with the LR model.
Our prediction results, Tables 2 and 3, show that **5,091** people were correctly predicted for a stroke, meaning they had a stroke as expected. These results show **100%** accuracy. Of the **320** patients who did not have a stroke, only one was

Table 3: Classification Table of Predicted

	Predicted		
Groups	Stroke	Non- Stroke	PercentageCorrect
Stroke	5091	0	100%
Non- Stroke	319	1	0.3%
Overall	(5091+1)/5411		94.1%

Table 4: Variables in the Equation

Risk factors	B	S.E	Wald	Sig.	Exp(B)
R`1	0.667	0.119	30.760	0.000	1.948
R`2	-0.321	0.074	18.873	0.000	.725
R`3	0.180	0.139	1.683	0.195	1.197
R`4	-0.759	0.219	11.986	0.001	0.468
R`5	-0.362	0.525	0.475	0.491	0.696
R`6	-1.145	0.729	2.471	0.116	0.318
R`7	-1.388	0.720	3.721	0.054	0.250
R`8	-0.391	0.471	0.690	0.406	0.676
R`9	-0.564	1.036	0.296	0.586	0.569
R`10	-0.297	0.150	3.953	0.047	0.742
R`11	-1.362	0.718	3.598	0.058	0.256
R`12	0.573	0.143	16.037	.000	1.773
R`13	1.302	1.163	1.253	0.263	3.678
R`14	-1.671	1.013	2.719	0.099	0.188
R`15	2.362	1.442	2.685	0.101	10.612
R`16	-18.778	7943.302	0.000	0.998	0.000
R`17	0.157	0.365	0.185	0.667	1.170
R`18	-0.276	0.125	4.869	0.027	0.759
R`19	0.142	0.129	4.869	0.027	0.759
R`20	0.050	0.275	0.033	0.857	1.051
R`21	-0.079	0.341	0.053	0.817	0.924
R`22	-0.151	0.060	6.405	0.011	0.860
Constant	44.807	15886.604	0.000	0.998	2.879E + 19

diagnosed correctly. However, **319** people were diagnosed with errors.
The overall prediction error was **5.89%**. Part of this error may be associated with the error on the data collected and recorded.
The Enter algorithm with the criterion $\alpha = 0.05$ for the adaptation of LR model was implemented on the observations. The results of implementing the algorithm are listed in Table 4 for all risk factors. The columns of Table 4, B, and SE show non-standard regression coefficients and standard error, respectively. Wald's column lists

the statistics that are most important to meaningfully test for the presence of any independent variable in the model. Column Exp (B) contains the standardized regression coefficient used to interpret the results. According to WALD statistic column and the significant $\underline{\alpha \leq 0.05}$ level, only 9 out of 22 factors are effective in the stroke occurrence and the rest have no direct impact on the disease.

According to WALD statistics and the significant level, out of **22** risk factors, only **9** risk factors are effective on the incidence of stroke and the rest of the variables are not included in the model.

The effective risk factors are shown in Table 4.

The column chart of Table 3 is plotted in Figure 1. The frequency of each of the four groups is indicated on the vertical axis and their percentage has been specified on the horizontal axis. The classification and prediction accuracy of the

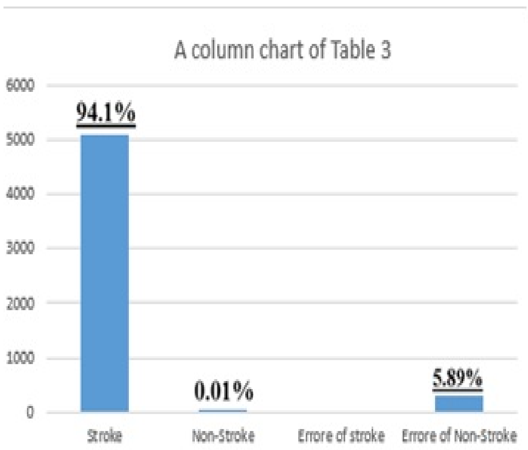

Figure 1: The column chart of prediction

model, known as the classification histogram, is shown in Figure 2. In this figure, N and Y represent a patient with non-stroke and stroke respectively. Aggregation of a group of responses on one side of the chart represents a higher accuracy of the classification and prediction. Using the extracted risk factors of Table 4, model (3.2) can be rewritten as follows.

$$P(y=1) = Logit(p) = ln(\frac{p}{1-p}) = \frac{e^{(44.807+0.667(R_1),\cdots,-0.151(R_{22}))}}{1+e^{-(44.807+0.667(R_1),\cdots,-0.151(R_{22}))}}$$

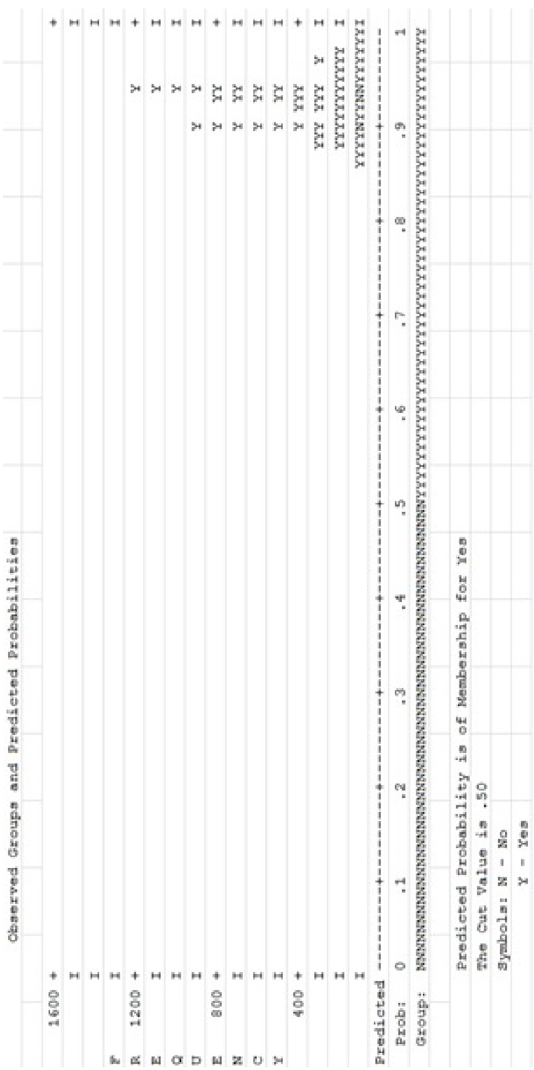

Figure 2: The classification histogram

where that,

$R_1 : Hypertension,$

$R_2 : DiabetesMellitus,$

$R_4 : AtrialFibrillation,$

$R_7 : CongestiveHeartFailure,$

$R_{10} : PreviousCerebrovascularAccident$

$R_{11} : PreviousTransientIschemicAttack,$

$R_{12} : Hyperlipidemia,$

$R_{18} : Smoking,$

$R_{22} : Snoring.$

are entered in above relation.
Each new observation with the corresponding values can be classified according to the validity of the model (94.1%) into one of two categories of occurrence or non-occurrence of stroke using the proposed model.

5 Conclusion

So far, research and studies have been conducted on the application of statistical and analytical methods in health, but researchers have not paid much attention to the prediction of stroke using clinical risk factors based on a prediction model. 5,411 patients represented the study population in this study. After consultation with neurologists and a review of the literature , 22 qualitative risk factors were selected. The most important outcome of this research is that the LR proposed model is able to predict the occurrence or non-occurrence of stroke with a confidence level of 94.1% using independent variables. The proposed model may be useful for those with symptoms of stroke and seeking medical advice. The final model presented in this study could predict the likelihood of stroke using clinical factors approved by a physician's experience. Unfortunately, patients due to lack of knowledge of stroke symptoms and insufficient counseling are unwilling to undergo regular medical examinations, so this specialized model can predict if a stroke occurs or not.

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