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RESEARCH ARTICLE

ESTABLISHING AND EVALUATING THE ARTIFICIAL NEURAL NETWORK MODEL FOR THE PREDICTION OF URINARY TRACT INFECTION AFTER UPPER URINARY CALCULI SURGERY

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Abstract

Objective: To establish and evaluate the artificial neural network (ANN) model for the prediction of urinary tract infection after upper urinary calculi surgery.

Methods: A total of 350 patients with upper urinary tract stones were collected and divided into training group (n=280) and test group (n=70) according to the proportion of 4:1. The logistic regression (LR) model was used to screen the data by multivariate analysis. Factors with statistically significant would be screened out to establish the LR model and artificial neural network (ANN) model. Receiver's operation curve (ROC) was used to evaluate the predictive effect of the model.

Results: A total of 29 cases (10.36%) developed postoperative urinary tract infections. Further analysis by logistic regression revealed that the following indicators were independent risk factors for urinary tract infection after upper urinary calculi surgery: infectious stones (OR=3.58, 95%CI=2.04-4.87; p<0.001), operation time (OR=1.51, 95%CI=1.11-2.06; p=0.01), preoperative urine white blood cells and nitrite are both positive (uWBC+NIT+) (OR=1.97, 95%CI=1.55-2.76; p=0.005), female patients (OR=1.55, 95%CI=1.03-2.35; p=0.04), preoperative positive urine culture (OR=1.33, 95%CI=1.20-1.73; p=0.03) and calculus with polyp encapsulation (OR=1.11, 95%CI=1.05-1.21; p=0.03). Furthermore, we have successfully established the ANN model for the predicting of urinary tract infection after upper urinary calculi surgery. When compared ANN model to LR model for the accurate of prediction by 70 patients in the test group, the accurate of prediction were 78.92% (LR) and 88.69% (ANN), respectively. Moreover, the area under the ROC curve (AUC) of ANN model was greater than the LR model (0.93±0.02 vs 0.74±0.05, p<0.01).

Conclusion: The established ANN model owned highly effectiveness and accuracy in the predicting of urinary tract infection after upper urinary calculi surgery.

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Introduction:-

Upper urinary tract stones, a global common disease, are one of the most common diseases of the urinary diseases. Epidemiological investigations in Europe and the United States showed that the prevalence of upper urinary tract stones was as high as about 10% [1, 2]. Epidemiological studies in China indicated that the incidence of urinary tract stones has increased by 40% in the past 20 years [3, 4]. However, the treatment methods have been rapidly changed from traditional open surgery to minimally invasive surgery (MIS) due to surgeons' efforts. At present, the most important surgical methods for upper urinary tract stones include percutaneous nephrolithotomy (PCNL) and flexible ureteroscope lithotripsy (FURL) [5-7]. However, even we have carefully treated about the potential infection risks by antibiotics and other methods, the above-mentioned operations always face the risk of postoperative infectious complications. Reports have confirmed that preoperative urinary tract infection is an important reason for severe infectious complications after surgery. According to the EAU guidelines, patients without preoperative urinary tract infection should be treated with a single dose of antibiotics to prevent postoperative infection, and patients with preoperative urinary tract infection should be treated according to urine culture for their urinary tract infection before surgery. Although the use of antibiotics before surgery has made the urine sterile, postoperative infections of stones are still inevitable [8, 9]. At present, there is insufficient research on the risk factors of postoperative infection of upper urinary tract stone. Moreover, it is a lack of means to early predict the postoperative infection [10-12]. Therefore, we have established an artificial neural network model to clarify the risk factors of postoperative infection. It would be hoped to find the early and rapid prediction method of infection after stone surgery.

Materials and Methods:-

Inclusion Criteria:

A total of 350 patients with upper urinary tract stones who underwent surgical treatment at the Department of Urology, Zigong Fourth People's Hospital between September 2018 and September 2020 were included. Patients were divided into training group (n=280) and test group (n=70) according to the proportion of 4:1, which were used to screen potential variables, establish predictive models, and test and evaluate models. The included criteria included the following characters: (i) All patients included were received CT scan before surgery. (ii) All patients have a score of 1-2 from the American Society of Anesthesiologists (ASA); (iii) There were no any abnormal coagulation function and immune function. For patients with evidence of preoperative urinary tract infection, including urine routine or positive urine culture, they received regular antibiotic treatment for 3-10 days before surgery and adjusted the use of sensitive antibiotics based on the susceptibility results of urine culture.

Perioperative indicators:

The following information has been recorded: (1) Before surgery: age, gender, height, weight, history of diabetes and hypertension, history of previous surgery for ipsilateral renal stones, preoperative antimicrobial use, preoperative urine routine, preoperative urine culture results, preoperative hemoglobin, preoperative blood creatinine. (ii) Radiological results: stone's size, location, number, type, CT value, hydronephrosis. (iii) Intraoperative indicators: operation method, operation time, stone incarceration and calculus with polyp encapsulation, respiratory rate, heart rate, blood pressure. (iv) Postoperative indicators: white blood cells, hemoglobin, serum creatinine, postoperative infectious complications. All operations in this study were performed by senior doctors with the same level and experience.

Statistical analysis:

We defined the dependent variable of model as whether there was urinary tract infection after surgery during the univariate and multivariate logistic regression (LR) analysis. Indicators with significant statistical difference were initially screened out to construct the LR predictive model. Back propagation (BP) methods were considered as the main method to establish ANN prediction model. Samples in test group were adopted to confirm the efficiency of both LR and ANN model. Z test was used to compare the difference between the areas under the ROC curve. Statistical analyses were completed with SPSS 20.0 software, while the ANN model establishment were completed depend on Matlab 8.0 software.

Results:-

1 Basic characteristics:

A total of 280 cases, 116 females (41.43%) and 164 males (58.57%), with an average age of 52.76 ± 14.92 years were included in the training group. The average stone load was $1698.28 \pm 1381.37 \text{ mm}^2$. A total of 52 cases (18.57%) with infectious stones. 153 cases (54.64%) were ureteral stones. In the term of operation method, 37 cases (13.21%)

received PCNL surgery and the remaining 243 cases (86.79%) received FURL or URL surgery. The average operation time for all cases was 54.82 ± 27.15 (27-106) min. The average preoperative serum creatinine was 103.89 ± 67.38 $\mu\text{mol/L}$. Among the complications, 212 cases (75.71%) with hydronephrosis, 24 cases (8.57%) with diabetes, 61 cases (21.79%) with hypertension, 92 cases (32.86%) with polyp encapsulation and 114 cases (40.71%) with previously upper urinary tract surgery. The results of preoperative urine routine showed that 42 cases (15.00%) with both positive urine white blood cells and urine Nitrite (uWBC+NIT+), 62 cases (22.14%) with positive urine white blood cells and negative urine Nitrite (uWBC+NIT-).

Univariate analysis of urinary tract infective risks after upper urinary calculi:

Univariate analysis found that the potential risk factor of postoperative infection of urinary tract stones surgery were: female patients ($p=0.001$), PCNL method ($p=0.02$), average stone load ($p=0.03$), infectious stones ($p<0.001$), operation time ($p=0.01$), calculus with polyp encapsulation ($p=0.002$), preoperative urine culture positive ($p=0.004$), uWBC+NIT+ ($p<0.001$), uWBC+NIT- ($p=0.008$).

Table 1:- Univariate analysis of urinary tract infective risks after upper urinary calculi.

Indicator	All Pts. (n=280)	Infected (n=29)	Non-infected (n=251)	P value
Female	116 (41.43%)	20 (68.97%)	96 (38.25%)	0.001
Age/y-o	52.76 ± 14.92	51.49 ± 19.38	52.91 ± 21.87	0.73
Calculi Position				0.06
Renal	127 (45.36%)	18 (62.07%)	109 (43.43%)	
Ureter	153 (54.64%)	11 (37.93%)	142 (56.57%)	
Operation Method				0.02
PCNL	37 (13.21%)	8 (27.59%)	29 (11.55%)	
(F)URL	243 (86.79%)	21 (72.41%)	222 (88.45%)	
Average stone load/ mm^2	1698.28 ± 1381.37	1871.23 ± 995.03	1239.90 ± 1572.48	0.03
Infectious stones	52 (18.57%)	12 (41.38%)	40 (15.94%)	<0.001
Operation time/min	54.82 ± 27.15	59.71 ± 29.64	50.79 ± 16.85	0.01
Hydronephrosis	212 (75.71%)	25 (86.21%)	187 (74.5%)	0.16
Preoperative SCr/ $\mu\text{mol/L}$	103.89 ± 67.38	109.85 ± 71.94	101.45 ± 32.79	0.27
Diabetes	24 (8.57%)	2 (6.9%)	22 (8.76%)	0.73
Hypertension	61 (21.79%)	5 (17.24%)	52 (20.72%)	0.78
Calculus with polyp encapsulation	92 (32.86%)	17 (58.62%)	75 (29.88%)	0.002
Positive preoperative urine culture	114 (40.71)	19 (65.52%)	95 (37.85%)	0.004
uWBC+NIT+	42 (15.00%)	14 (48.28%)	28 (11.16%)	<0.001
uWBC+NIT-	62 (22.14%)	12 (41.38%)	50 (19.92%)	0.008

Multivariate logistic regression analysis:

Multivariate logistic regression analysis showed that the infectious stones (OR=3.58, 95%CI=2.04-4.87; $p<0.001$), excessive operation time (OR=1.51, 95%CI=1.11-2.06; $p=0.01$), uWBC+NIT+ (OR=1.97, 95%CI=1.55-2.76; $p=0.005$), female patients (OR=1.55, 95%CI=1.03-2.35; $p=0.04$), positive preoperative urine culture (OR=1.33, 95%CI=1.20-1.73; $p=0.03$) and calculus with polyp encapsulation (OR=1.11, 95%CI=1.05-1.21; $p=0.03$) are independent risk factors for the postoperative infection of upper urinary tract stones surgery.

Furthermore, the LR model was established with partial maximum likelihood forward method. The function was as following:

Logit (P) = $0.52 + 1.32(\text{infectious stones}) + 0.67(\text{uWBC+NIT+}) + 0.44(\text{female}) + 0.58(\text{operation time}) + 0.27(\text{positive preoperative urine culture}) + 1.11(\text{calculus with polyp encapsulation})$.

Table 2:- Logistic regression analysis of urinary tract infective risks after upper urinary calculi.

Factor	B	SE	Wald value	P	OR	95%CI
Female	0.44	0.21	4.43	0.04	1.55	1.03-2.35
Calculus with polyp	0.18	0.06	8.91	0.03	1.11	1.05-1.21

encapsulation						
Infectious stones	1.32	0.37	15.63	<0.001	3.58	2.04-4.87
Operation time	0.58	0.14	5.70	0.01	1.51	1.11-2.06
uWBC+NIT+	0.67	0.13	7.21	0.005	1.97	1.55-2.76
Positive preoperative urine culture	0.27	0.10	3.09	0.03	1.33	1.20-1.73

ANN model Establishment:

According to the degree of influence for network, input factors were used to make the sequence diagram (Figure 1). The degree of influence in descending order was: Infection stones, uWBC+NIT+, female, operation time, positive preoperative urine culture, calculus with polyp encapsulation

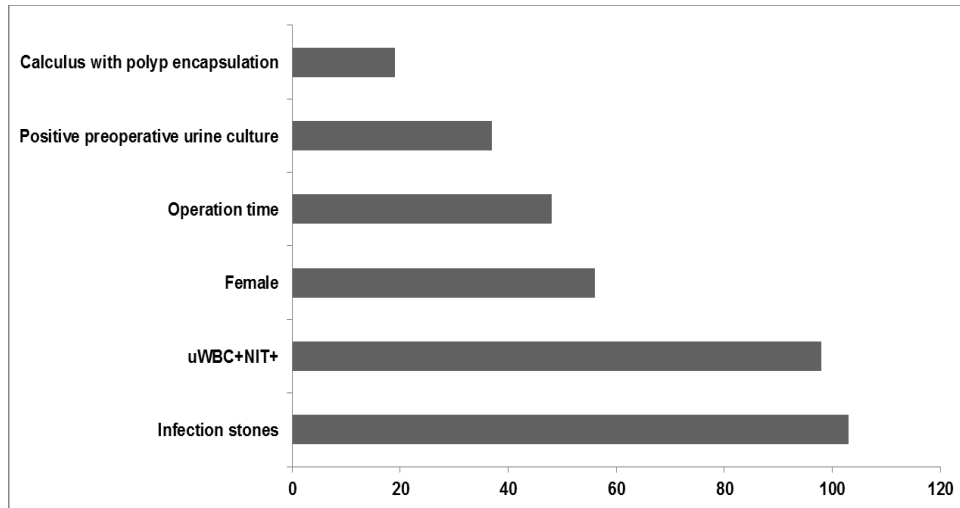


Figure 1:- Sensitivity analysis of ANN input variables.

The 6 independent variables selected by the above LR regression analysis were used as input elements and postoperative infection as output elements. The 3-layer feedforward BP neural network was directly constructed. Six neural nodes in the input layer were as following: Infectious calculus, uWBC+NIT+, female, operation time, positive preoperative urine culture, calculus with polyp encapsulation. Hyperbolic tangent transfer function was used in the six hidden layer nerve nodes. Softmax transfer function was used in the binary output variable- whether there was postoperative urinary tract infection. The hidden layer transfer function was Tansig and the output layer transfer function was Purelin. The target error was defined as 0.01 and the learning rate was defined as 0.1. The LM optimization algorithm was used in the training of network.

Predicting results of ANN model:

To evaluate the efficiency of ANN model, the area under the ROC curve of both LR regression model and ANN model were calculated and compared. Results identified that the area under the ROC curve of ANN was greater than that of LR model. There was significant statistical significance (0.93 ± 0.02 vs 0.74 ± 0.05 , $P < 0.01$, Figure 2).

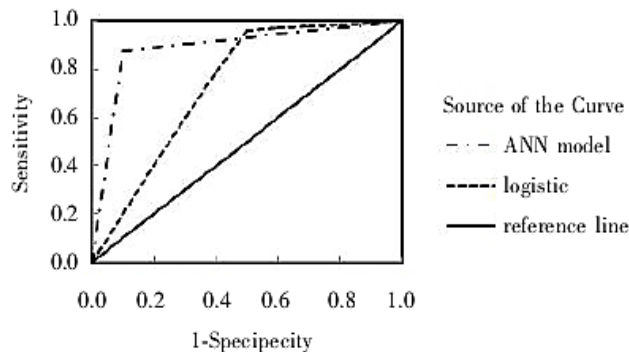


Figure 2:- ROC curve of ANN and logistic regression model.

Evaluation of model prediction results:

Evaluating results with 40 test samples identified the ANN model established above were prior to LR model in the terms of accuracy (88.69% vs 78.92%, $p < 0.05$), sensitivity (94.51% vs 52.36%, $p < 0.05$) and Youden index (83.41 vs 47.91, $p < 0.05$). Nevertheless, the specificity of the ANN model is lower than that of the LR model (85.72% vs 92.68%, $p < 0.05$; Table 2).

Table 3:- Evaluation indicators of prediction results of ANN model and logistic model (%).

Model	Accuracy (%)	SEN (%)	SEP (%)	Yorden index
LR	78.92	52.36	92.68	47.91
ANN	88.69	94.51	85.72	83.41

Discussion:-

Postoperative infection is one of the most common complications after urinary stone surgery[13, 14]. At the same time, postoperative urinary infection is also one of the most common complications. With the continuous updating and improvement of surgical instruments and device, minimally invasive surgical techniques gradually prevented patients suffered from open surgery[15]. The incidence of operation related complications has been significantly dropped down. However, due to the lack of good methods that can effectively prevent postoperative infection, it is always an unavoidable problem[16, 17]. In addition, during the surgery for urinary calculi, the integrity of urothelial mucosa of ureter or collecting system could be destroyed in varying degrees[18-20]. Therefore, it would be more chance to meet postoperative infection.

This study attempted to establish a specific mathematical model using the risk factors that affect the occurrence of infection after upper urinary calculi. This model was used to evaluate and predict the possible infections of patients with upper urinary tract stones. LR model was simple and easy to use, and it was the most commonly used method for predicting diseases with clear classification. However, the LR model requires data to meet more stringent conditions, and it is difficult to effectively predict the occurrence of infections in individual patients. However, the ANN model has received widely attention from medical workers in disease prediction, and its characteristics are there are no requirements for the distribution and type of variables during the model establishment. The ANN model was good at dealing with non-linear, fuzzy, and noisy data situations. It also provided a new way to solve complex medical problems. Relevant research confirmed that the BP artificial neural network fits the data far better than the traditional COX regression and LR models.

In the present study, the risk factors selected by the conditional LR regression analysis were used to establish the LR and ANN prediction models, and the test set samples were used for detection. The research results showed that ANN model were better than LR model in the terms of overall accuracy, sensitivity and Youden index. This study has used the ROC curve to evaluate the prediction effects of two models; the ROC curve can intuitively observe the relationship between sensitivity and specificity. The larger the area under the curve, the greater the accuracy of the diagnostic test. The results of this study showed that the LR prediction model ROC curve. The area under the ROC curve is 0.74 ± 0.05 , and the area under the ROC curve of the BP neural network prediction result is 0.93 ± 0.02 , which indicates that the ANN prediction model has better prediction and discrimination performance than the LR prediction model.

Since the retrospective nature, the definition of patient infection was mainly based on the diagnosis and the medical record, as well as the radiological or laboratory examination. There were still some cases with antibiotic therapy and without sufficient evidence. Therefore, this may cause information limitations and selected bias, resulting in certain defects in the established predictive model. Further prospective study would be conducted base on this model and constantly update this model.

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Availability of data and materials:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests.

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