Original Article Discrimination analysis of B-mode ultrasonography and X-ray on the percutaneous nephrolithotomy localization of urinary stones: a prospective, controlled study

Gang Li, Zhongweng Liu, Yang Zhang, Zhiyong Chen, Peng Hu, Qiang Chen, Wei Ding

Department of Urology, Mianzhu, People's Hospital, Sichuan, China

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Abstract: The role of B-mode ultrasonography and X-ray on the percutaneous nephrolithotomy (PCNL) localization of urinary stones is controversial. This study aimed to evaluate the best choice between X-ray and B-mode ultrasonography on the PCNL localization of urinary stones. We trained a back-propagation artificial neural network (ANN) to evaluate the best localizing method for a specific patient. Prospective demographic data from patients and pre-operative stone or renal characteristics were used to build the network, and the network was tested using unseen data. Two hundred eight patients were enrolled in the ANN training, and 47 patients were used for testing. The trained network was able to enhance the success rate of puncturing in complex or smaller kidneys in the training and test sets. The combined method was not significant superior in the management of large or simple stones (P < 0.05). Puncture localization of complex or smaller renal stones by B-mode ultrasonography combined with X-ray being the recommended, while localization for simple or large stones only needs one of the two methods, with X-ray being the recommended method.

Keywords: Discrimination analysis, percutaneous nephrolithotomy, B-mode ultrasonography, urinary stone

Introduction

Percutaneous nephrolithotomy (PCNL) has been accepted as the recommend procedure for management of renal stones since 1976 [1]. Traditionally, PCNL is performed under X-ray guidance [2]. PCNL increases positioning of the three-dimensional space, while PCNL has also increased the exposure of surgeons and patients to the possible deleterious radiation effects. To avoid or decrease radiation effects, highly advanced protective shields or ultrasonography (USG) are available [3]. USG can be useful to identify radioparent calculi, as well as access the collecting system and evaluate dilatation of the genitourinary [ok?] tract; however, the three-dimensional assessment [ok?] is inferior to X-ray. Furthermore, USG-guided PCNL can reduce the harmful effects of X-rays intra-operatively. In some situations, combination of the two methods in PCNL will yield a better effect. Hence, which type of patient is suitable for X-ray or USG is controversial. An artificial neural network (ANN) is a computational model inspired by the central nervous systems (CNSs) of animals that are capable of machine learning and pattern recognition [4-6]. ANNs are usually presented as systems of interconnected "neurons" that can compute values from inputs by feeding information through the network. An ANN can be used in risk factor prediction or discrimination analysis in medicine [7]. The present study aimed to make an ANN to determine the proper method for evaluating patients with urinary stones. [ok?]

Material and methods

Patient characteristics

Between April 2010 and December 2013, a total of 312 patients who were candidates for PCNL were randomly divided into the following 3 groups: a B-mode ultrasonography (BUG) PCNL group (BUG); a standard X-ray-guided PCNL group (PCNL); and a combined BUG and X-ray-guided PCNL group (combined). The inclusion criteria were as follows: (i) kidney stones >

2 cm in size; (ii) complete or incomplete staghorn calculi; (iii) symptomatic renal calyx or diverticulum calculi; (iv) difficulty crushing the stone with extracorporeal shock wave therapy or treatment failure; and (v) upper ureteral calculi. The exclusion criteria were as follows: (i) patients with a tendency to systemic hemorrhagic; (ii) respiratory insufficiency; (iii) lumbarkidney distance > 20 cm; and (iv) severe spinal deformity. All of the patients were randomly divided into the above groups through computer-generated numbers before the clinical trials commenced, and all of the included patients signed informed consent. An ethics statement was necessary. The main pre-operative preparation included a urologic USG and a kidneyureter-bladder (KUB) radiologic examination. Intravenous urography or abdominal computed tomography were sometimes necessary.

Surgical technique

A lithotomy position was assumed to place the 5-French ureteral catheter into the ureter under the cystoscope. Then, the patients were placed in the prone position and disinfected with sterile towels.

BUG-guided PCNL

We use an ALOKASSD-500 B ultrasonic guidance UST-934N with 3.5 MHz probes [city, state, country?] intra-operatively scan with a sterile plastic sheath for cavity mirrors outside. The ultrasonic medium was sterile saline. To expand the renal collecting system and serve as an artificial kidney effusion, the assistant injected the sterile saline solution through the retained ureter catheter. First, we used the ultrasonic probe for a longitudinal scan of the kidney and the small of the back. When the renal pelvis was localized, we defined the renal pelvis at the level connecting the axillary line and back at the intersection between the horn line under the shoulder area as the targeted area. To avoid the ribs, we removed the probe from the pierced area and turned the direction of the scan parallel to the floor. Then, we scanned the structure of the puncture channel, measured the distance of the skin to the targeted calvces, and measured the thickness of the renal parenchyma to evaluate the direction, angle, and depth of the needle. Then, we made the puncture in accordance with the ultrasonicguided angle and depth with an 18 G puncture trocar. After hitting the target calyces, we visualized the urine and saline outflow, placed the guide wire, and routinely expanded the channel by the sheaths, which began with the 6F in diameter. Finally, we inserted the endoscope into the expanded channel.

X-ray-guided PCNL

A caliceal puncture was performed under C-arm fluoroscope guidance after pelvicaliceal system opacification through the ureteral catheter. Other surgical steps were performed that were similar to the BUG technique. Residual stones were evaluated by X-ray at the completion of the procedure.

Combined guided PCNL

A BUG examination was preferentially used to evaluate the position of the kidney and the relationship between the adjacent organs, and to determine the target calyces. We used the BUG examination to evaluate the puncture location, distance, and direction. Then, we used the renal puncture needle to prick the skin and retrograde inject the contrast agents through the previously placed indwelling ureteral catheter. Kidney puncture was monitored under a C-shaped arm X-ray. During the puncture, the surgeon estimated the puncture direction and needle depth, and confirmed that the needle tip was not over the collecting system. The puncture was considered successful when there was urine overflow. Surgeons can clearly distinguish whether or not the zebra godet has picked out the collection system under the X-ray monitor.

All of the patients underwent a kidney-ureterbladder (KUB) X-ray examination and USG examination on the first post-operative day to evaluate residual stones. The primary success rate included the patients after the first session of PCNL who were stone-free or residual stone diameter < 5 mm. Plain KUB X-ray and USG were performed 2 months after surgery. The second PCNL or extracorporeal shockwave lithotripsy was adopted to manage residual stones > 2 cm in size.

Univariate factor analysis

In the current study, the primary end points were the success and complication rates.

Percutaneous nephrolithotomy localization



Figure 1. Network construction by back propagation method.

Indicator	BUG	X-ray	Combined	P value
No. of patients	103	105	40	NA
Mean age (yrs)	95.8±34.1	78.5±29.4	101.5±16.8	0.13
BMI (kg/m ²)	24.3±2.1	22.5±2.4	23.7±1.6	0.08
Obesity	35	21	15	0.04
Gender				0.28
Male	56	61	19	
Female	47	44	21	
Stone side				0.07
Left	40	29	41	
Right	25	11	14	
Stone location				0.31
Upper calices	26	31	14	
Middle calices	41	47	15	
Lower calices	36	27	11	
Hydronephrosis degree				0.03
Mild	10	18	5	
Moderate	15	14	11	
Serious	31	6	9	
Diabetes	12	10	5	0.28
Cardiovascular	21	18	8	0.12
Previous abdominal surgery	5	3	1	0.19

Table 1. Comparison of basic characteristics

BMI, body mass index; NA, not available.

Secondary end points included the length of hospitalization and operative time. Possible factors governing the choice BUG or X-ray include age, body mass index (BMI), stone site, stone side, stone diameter, and degree of hydronephrosis. Data were priority analyzed using SPSS software (version 20.0). Student's t-test or the chi-square test, as appropriate, was used for data analysis.

Multiple variable regression

Multivariate regression (MV-R) is designed to evaluate the further relationship between the dependent or criterion variable and potential predictor variables. The purpose of regression analysis is to confirm the value of a parameter as a function, and this function provides a data group for observation. A function would be a linear equation in a linear regression. MVRs were used to formulate the best-fit function in the multiple independent variables.

Network construction

The ANN was established by Matlab software. The algorithm was based on the most common BP algorithm, which is widely used in biological scientific research. The main procedure included the potential indicators as input variables. The number of middle implicit strata was only one because of the binary classification and multivariate decision in this study. The number of implicit strata neurons was based on the number of included variables of the model. Information transmission between input layer and

implicit strata was based on the log-sig function, which was called a S-function logarithm, while the information transmission between implicit strata and output layer was based on the purelin function (a linear function). The model construction step can be found in **Figure 1**. We use the unknown sample for model training and improvement after the model complement.

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Variable	OR	OR 95% CI	Р
BMI	0.46	0.08~2.01	0.24
Obesity	2.03	1.15~3.24	0.01
Diabetes	0.72	0.19~1.06	0.34
Cardiovascular	0.96	0.52~10.74	0.82
Previous abdominal surgery	0.71	0.28~32.09	0.16
Renal co-infection	1.02	1.00~6.58	0.03
Stone location	6.15	3.67~4.71	< 0.01
Stone side	1.09	0.94~14.62	0.59
Stone diameter	5.54	3.28~16.59	< 0.01
Degree of hydronephrosis	4.98	2.47~8.31	0.02

Table 2. Multiple variable regression results for potential variable

OR: odds ratio; CI: confidence interval.



Figure 2. Measured and predicted power by artificial neural network.

Results

Basic characteristics

A total of 248 patients were included in our study. Among these patients, 103 received PCNL under BUG, 105 received PCNL under X-ray guidance, and the remaining 40 patients received PCNL under the guidance of BUG combined with X-ray. The basic characteristics of the three groups are presented in **Table 1**.

Operative results

The mean wear needle in the BUG group was 2.3 times. A total of 92 cases had one-phase stone removal, and the radical removal rate

was 89.3%. Residual calculi occurred in 11 patients; the mean diameter of residual calculi was 0.8 cm. Extracorporeal shock wave lithotripsy (ESWL) was performed on these patients 1 month post-operatively, and all the stones were removal radically. The mean operative time was 95.8±34.1 min, and the post-operative hospital stay was 5.4±2.7 days. The serum creatinine (SCr) decreased to normal in 41 patients who had high-level SCr before surgery. No patients needed a transfusion. No major post-operative complications occurred in these patients. After 3 months of follow-up, there were no residual stones following X-ray- or BUG-guided PCNL.

The mean wear needle in the X-ray group was 1.9 times. The stones were radically removed in 100 patients; the radical removal rate was 95.2%. Residual calculi occurred in 5 patients; the mean diameter of residual calculi was 0.5 cm. ESWL was performed on patients with residual calculi 1 month

post-operatively, and all the stones were removal radically. The mean operative time was 78.5±29.4 min, and the post-operative hospital stay was 4.9±3.2 days. The SCr dropped to normal in 37 patients who had high-level SCr before surgery. There were two patients who needed transfusion during the operation; the mean volume of red blood cell (RBC) transfusion was 300 mL. One patient sustained a colon injury and the procedure was converted to an open surgery. After 3 months of follow-up, there were no residual stones following X-ray- or BUG-guided PCNL.

The mean wear needle in the combined group was 1.4 times. All of the patients in the com-



Figure 3. Measured and predicted power by multiple variable regression.

bined group had one-phase stone removal; the radical removal rate was 100%. The mean operative time was 101.5±16.8 min, and the post-operative hospital stay was 4.8±3.1 days. The SCr level dropped to normal in 19 patients, who had high-level SCr before surgery. There were no patients who needed transfusion. No major post-operative complications occurred in these patients. After 3 months of follow-up, there were no residual stones following X-rayor BUG-guided PCNL.

Multiple variable regressions results

Table 2 presents the MVR results. According to the following basic characteristics, we divided the patients into several sub-groups in each group, as follows: BMI; obesity; diabetes or metabolic disease; cardiovascular disease; previous abdominal surgery; renal co-infection; stone location; stone side; stone diameter; and the degree of hydronephrosis. MVR analyses revealed that obesity, renal co-infection, stone location, stone diameter, and the degree of hydronephrosis had a significant influence on the discrimination of the localization method (*P* < 0.01).

ANN model construction results

The predicted variables were poor correlation co-efficient by MVR. The ANN model between

the predicted and observed values were highly correlated with each other, as given in **Figure 2. Figure 3** shows a comparison of measured and predicted power and the number of the five predictors by ANN and MVRA, respectively.

Network model training

We developed network training to enhance the predicted power of the ANN model, and compared the ANN to the MVR model and the surgeon's experience in the prediction of the localization method of PCNL on 20 patients. The results showed that the peri-operative indicators of patients

under the ANN model were significantly better than patients under MVR or the surgeon's experience. The results are presented in **Figure 4**.

Discussion

The treatment of urinary calculi can be performed via ureteroscopic lithotripsy, ESWL. and PCNL [8]. PCNL is currently one of the major methods in the treatment of urinary stones. This method is associated with minor injuries and has a superior complete calculi removal rate when compared with traditional open surgery [9].

PCNL often requires positioning of the puncture angle and depth. Usually, the positioning method includes X-ray- or BUG-guided positioning. The X-ray-guided method is the most basic positioning maneuver. The procedure is simple and convenient to perform in most types of hospitals. The main advantage of X-ray- or BUGguided positioning is that renal pelvis-calyces expansion can be more intuitive to understand, as well as the stone position and its relationship to the renal collection system by pelvic angiography. It is helpful to determine the best kidney puncture point of judgment. In contrast, surgeons can detect the puncture depth, thread location, and the depth of spreader or balloons though X-ray fluoroscopy to avoid a false path of puncture, or a puncture that is too deep or



insufficient. However, there are several limitations of X-ray-guided PCNL. The physicians and patients will be exposed to radiation in the positioning process [10]. Moreover, X-ray-guided PCNL cannot display the adjacent organs in the puncture and this is a known cause of injury. Therefore, some scholars consider applying USG in the positioning of PCNL, which has no associated radiation exposure.

When compared to traditional X-ray, BUG is non-invasive and can facilitate multi-angle observation of the kidney. Frequently, BUG can display the structure of the renal calyx perfectly, especially for the dilated renal calyx or renal calyx with calculi. An USG guidance system can also automatically calculate the distance from the skin biopsy to the kidney puncture [11]. In theory, BUG should be more conducive to selecting the puncture needle depth and angle of the targeted calyces; however, the BUG image is more difficult to identify than X-ray, and the image definition is highly affected by the experience of the operator. In addition, the design of the surgery approach is less intuitive than X-ray. The BUG image is poorer than X-ray in the monitoring of thread intra-operative procedure. Edema or peri-renal bleeding after repeated puncture may occur, and in this case, identification of the location of renal calyces and stones when using BUG, and the positioning of the pleura is less than X-ray [12].

The goal of PCNL is to remove the calculi as thoroughly as possible; the stone of post-operative residual is the gold standard for evaluating the effect of surgery. To achieve calculi removal and reduce the complications, accuracy is needed when performing the puncture location. Krombach et al. [13] used a magnetic field in locating stones in a porcine model. The literature reports that USG-guided puncture positioning has achieved better puncture location, while some scholars have achieved a better effect when combining BUG and X-ray in puncture positioning. The main step of this method involves using BUG to scan the puncture location area to better understand the status of calculi distribution, kidney structure, and adjacent organs. Then, a preliminary determination of the targeted renal calyces and puncture angle can be determined. A puncture is then made into the renal calyces under USG guidance. Finally, in the BUG procedure, the surgeons inject the contrast agent into the renal calyces through the needle. The surgeons can assess the puncture angle or depth through the X-ray and undergo the subsequent thread establishment of the artificial channel. The patients in this study were limited in number and poor in randomization; the conclusions are worthy of further study. Moreover, there are no reports on the puncture-guided method in patients with different BMIs, different stones, or renal calyces. Hence, we have made the first discrimination analysis to supply a basis for choosing BUG or X-ray.

An ANN was used rather than genetic algorithms, expert systems, and case-based reasoning. ANN is a division of the "Artificial Intelligence" [14]. The ANN model is an information processing system in the medical research that simulates the functions and structure of intellect [15]. This model attempts to simulate the human brain in the complex works, which was dependent on the computer program [16].

The need for contrast is eliminated, and the depth of the kidney can be evaluated with more accurate access to the PCNL without injury to the adjacent organs when using USG guidance [17]. In addition, the contrast may overlie the opacity of the stone and may cause confusion when extravasation occurs because of the inability to recognize the punch card system [18].

The advantages of US over fluoroscopy-guided access into the collecting system include elimination of exposure to radiation for the urologist and operating room personnel. In pregnancy, this method of access to the kidney is feasible. In patients with transplanted, horseshoe, and ectopic kidneys, it may be an acceptable method of access. Other advantages of USG are detection of non-opaque stones, which are not visible with fluoroscopy, and also proper localization of the adjacent organs for prevention of injury. The main disadvantage of this modality is difficulty with the approach to a punch card system with mild dilatation and need for more care.

Scholars have used USG for primary access to the collecting system [19], but tract dilatation has been performed under the guidance of fluoroscopy. USG-guided PCNL can be a feasible, reliable, safe, and effective alternative to fluoroscopy in experienced hands and decrease radiation exposure to both the urologist and the patient [20]. We suggest the use of fluoroscopy in difficult cases and at least a single visualization with fluoroscopy for determining the optimal stone-free state at the end of the procedure in USG-guided PCNL.

In conclusion, we used the ANN model to predict a PCNL localization method, and make comparisons with the traditional multiple variable regression and surgeon's experience only. The results show that this model is more stable than MVRA, and the predictive value is significantly higher than the other method. Due to the self-learning character of this model, it would be a significant improvement of the efficacy and peri-operative indicator when using this model in the PCNL in future practice.

Disclosure of conflict of interest

None.

Address correspondence to: Gang Li, Department of Urology, Mianzhu, People's Hospital, Sichuan, China. Tel: +860838-5987921; Fax: +860838-5987921; E-mail: gang_li_gg@sina.cn

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