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ANALYSIS OF THE EFFECT OF ARTIFICIAL INTELLIGENCE-ASSISTED MINIMALLY INVASIVE TREATMENT FOR URINARY CALCULI

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Abstract: Urinary calculi, a prevalent urinary system disorder, significantly impairs patients' quality of life and exhibits an escalating incidence. While minimally invasive surgery offers clinical advantages, it is challenged by complications, high costs, and inconsistent standards. This study explores the role of artificial intelligence (AI) in enhancing minimally invasive treatment for urinary calculi, addressing unmet needs in precision and efficacy.Using a systematic analysis, the research examines AI applications across the treatment continuum: preoperatively, AI predicts stone composition, evaluates size/location, and optimizes surgical strategies through data-driven models; intraoperatively, it enhances procedural safety and outcomes via real-time decision support; postoperatively, AI aids risk assessment for recurrence and guides personalized follow-up to reduce complications. Findings reveal that AI integration improves treatment customization and precision by synthesizing multi-dimensional clinical data, yet challenges persist, including model accuracy limitations, standardization gaps, variable physician proficiency, and economic barriers.Innovatively, this study highlights AI's potential to transform holistic management of urinary calculi while identifying critical implementation hurdles. It underscores the need for technological refinement, standardized protocols, clinician training, and cost-containment measures to facilitate widespread adoption. By bridging AI capabilities with clinical practice, this analysis provides a practical framework for advancing minimally invasive therapies, ultimately aiming to enhance patient care through evidence-based, AI-driven solutions.
Keywords: Urinary calculi; Minimally invasive surgery; Artificial intelligence; Assisted treatment

1 INTRODUCTION

Urinary calculi are one of the most common urinary system disorders, not only significantly affecting the quality of life of patients, but also causing a series of complications, including urinary tract obstruction, pain, nausea, vomiting, and sepsis. The common causes are urinary retention, infection, the presence of foreign bodies, dehydration, diet, and inactivity [1]. Therefore, timely and effective treatment of urinary calculi has become an important task in clinical medicine.

Traditional treatments for urinary calculi include drug therapy and non-drug therapy. Non-drug therapy, such as surgical treatment, has obvious advantages over drug treatment. Surgical treatment of urinary calculi has the advantages of higher treatment efficiency, rapid symptom relief, and reduced risk of recurrence when dealing with large and complex calculi. Surgical treatments include pyelotomy or renal sinus lithotomy, partial nephrectomy, and ureterotomy. Each of these methods has its advantages and disadvantages, and the therapeutic effect varies depending on the size and location of the stone and the overall health of the patient. With the continuous advancement of technology, minimally invasive surgery is receiving increasing attention in the treatment of urinary calculi, including extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotripsy (PCNL), and cystoscopic lithotripsy. Replacing open surgery with minimally invasive techniques for treating renal calculi has significantly reduced morbidity and mortality, as well as hospitalization and recovery periods for patients. If extracorporeal shock wave lithotripsy does not require anesthesia and almost no analgesia, it can be treated in the outpatient department, and there are no wounds to heal. Percutaneous endoscopic lithotomy requires only a small puncture site and has few complications with the advent of prophylactic antibiotics [2].

Artificial intelligence (AI), as a cutting-edge technology, deeply simulates human intelligence. Through algorithms and models, machines are endowed with the ability to learn knowledge independently, solve logical problems, and make precise decisions. It is highly effective in many fields such as healthcare, transportation, and finance. Its rapid development has provided new solutions for the diagnosis and treatment of urinary calculi. Through big data analysis and machine learning algorithms, AI can help doctors identify stones more accurately in imaging examinations, assess the nature of stones, and predict postoperative outcomes for patients.

Although minimally invasive techniques have made significant progress in recent years, they have been continuously improved, such as the development of more advanced endoscopes and lithotripsy equipment, which have enhanced the efficiency and safety of stone removal, such as using AI to predict the size, location, and future development of stones. Although minimally invasive surgery is generally minimally invasive, there is still a risk of postoperative complications such as bleeding, infection, and damage to surrounding organs, which can affect the recovery of patients and the promotion of the surgery. The persistence, development, or recurrence of complications such as recurrent urinary tract infection (UTI), urinary retention, stones, hematuria, and urinary incontinence may also indicate the failure of minimally invasive treatment [3]. Lower stone clearance rate and higher re-treatment rate of shock wave lithotripsy (SWL) when dealing with larger stones. At the same time, minimally invasive surgery may require higher equipment investment and maintenance costs compared to traditional surgery, making it difficult to fully promote economically. There is also a lack of unified clinical application guidelines and standards for what types of stones are suitable for minimally invasive surgery, which may lead to a less reasonable choice of treatment options. There is a lack of research on minimally invasive surgery in the long-term effect evaluation, and more clinical data are needed to support its efficacy and safety.

This study will conduct a systematic analysis of urinary calculi treatment methods based on AI-assisted minimally invasive techniques, aiming to provide references for clinical practice and identify the limitations, directions, and prospects of AI development, and this will provide some assistance and guidance for the clinical treatment of urinary calculi.

2 PREOPERATIVE DIAGNOSTIC ANALYSIS

2.1 Prediction of Stone Composition

Accurate determination of the composition of urinary calculi is of great significance for formulating personalized treatment plans. Traditional stone composition analysis is usually carried out after the stones are removed, and the process is rather cumbersome. AI technology, through in-depth analysis of multi-dimensional data such as patients' clinical data and imaging features, can predict the composition of stones before surgery, including computed tomography (CT) images, endoscopic images, direct images, X-rays, and smartphone micrographs [4]. A variety of AI models can be used, such as artificial neural network (ANN), convolutional neural network (CNN), deep learning models, machine learning, and SVM. It was found that the average accuracy rate of the 35 AI models used in the 14 original studies was 88.2%. Compared with traditional stone composition analysis, AI-assisted stone composition analysis is more accurate and convenient, and different models have their own advantages for different data, all contributing to the precise prediction of stone composition. This indicates that AI can provide clinicians with valuable preoperative information, providing a basis for them to choose more appropriate treatment methods.

2.2 Analysis of Stone Size and Location

Precisely determining the size and location of urinary calculi is crucial for formulating the surgical plan. AI technology has shown high accuracy and efficiency in this regard. In determining stone volume, Yenikekaluva et al. conducted a retrospective study of non-enhanced CT (NCCT) -KUB scan data from 494 patients over 18 years old and used AI-driven UrologiQ software to calculate stone volume [5]. Compared with radiologists' measurements, patients' personal information was removed during data processing, and some of the data were manually split by ITK-SNAP software to calculate volume for cross-validation. The results showed an intra-group correlation coefficient of 0.999 between AI and human validators, and a Dice score of 0.936, indicating high consistency between the two. In addition, the trends of AI and radiologists in evaluating the Hounsfield unit (HU) value of stones were similar, and the correlation between the volume measured by AI and the results calculated by both human validators and radiologists was strong (p values were all less than 0.001). This indicates that AI measurement of kidney stone volume is more accurate, efficient, and consistent than manual calculation by radiologists, which can improve diagnostic accuracy and surgical planning and help promote the standardized application of volume measurement in clinical practice. In the future, it can be combined with advanced imaging equipment to further optimize diagnosis and treatment processes.

2.3 Screening of Treatment Strategies

AI is also very important for the analysis of treatment strategies in the preoperative planning of urinary calculi. With the help of deep learning algorithms, AI can precisely interpret patients' CT, magnetic resonance imaging (MRI), and other imaging data, identify the location, size, shape, and quantity of stones, and analyze the anatomical relationship between stones and surrounding tissues. Alexander et al. analyzed the treatment outcomes of 625 patients with kidney stones, created registers containing more than 50 parameters for each patient, and used them as the basis for training neural network evaluation techniques [6]. To assess the potential of the neural network algorithm in choosing surgical treatments for urinary calculi, the results showed that the technique helped urologists select the best treatment for each patient, thereby minimizing the risk of early postoperative complications.

3 AI-ASSISTED MINIMALLY INVASIVE SURGERY

3.1 Shock Wave Lithotripsy (SWL)

SWL is one of the most widely used stone treatment techniques. With the continuous development of technology and the continuous improvement of equipment, its therapeutic effect and safety have been further enhanced, and its application scope has been expanded, occupying an indispensable position in the comprehensive treatment system for urinary calculi. The assistance of AI is an indispensable part of its development.

Nakamae et al. used a nonlinear support vector machine (SVM) algorithm in their study, using preoperative non-enhanced computed tomography (NCCT) data from 171 patients with ureteral calculi, including three non-automatic measurement factors: patient age, distance from skin to calculi, and thickness of the ureteral wall [7]. AI predicts the outcome of SWL by analyzing these multi-dimensional data, including 12 automatic measurement factors such as stone volume, seven CT value statistical parameters, and four gradient concentration factors, assisting doctors in judging the SWL treatment effect on patients before treatment. After five-fold cross-validation, the average area under the receiver operating characteristic curve (AUC) for the predictive performance of the AI model was 0.742, and the mean sensitivity to the stone-free state (SF) was 0.692 when the specificity was 0.733. Its advantages lie in its robustness to data diversity, its ability to effectively avoid errors caused by manual measurement factors, and its use of multi-factor prediction, which is more systematic than single-factor prediction and applicable in a variety of clinical scenarios, providing a valuable reference for the selection of clinical treatment plans.

In ESWL, precise focusing of stones is the core to improve the effect of lithotripsy. AI technology can automatically adjust the direction and energy of shock wave emission by monitoring the location of the stone and the patient's breathing movement in real time, achieving precise lithotripsy. The U - Net neural network can be used in two - dimensional ultrasound image analysis of ESWL [8]. The algorithm can determine whether kidney stones are in the focused area (FZ), enabling the lithotripsy machine to precisely emit shock waves, increase hit rate, reduce error rate, and make ESWL treatment more accurate and safer.

In terms of efficacy, the median hit rate of the standard ESWL was 55.2% (95% confidence interval 43.2 - 67.3%), which increased to 75.3% under the control of the U - Net algorithm, and the overall error rate decreased by 67.1%. In terms of classification performance indicators, the U - Net algorithm had an accuracy rate of 63.9%, a sensitivity of 56.0%, and a specificity of 74.7%. It performed well in the classification of “stones not in the focus area” and could accurately track stones, outperforming random guessing.

In terms of treatment time and hit counts, the treatment time of ESWL controlled by U - Net was 1.94 times that controlled by the operator, and the hit counts were 23 and 45 per minute, respectively. Due to the algorithm’s ability to reduce errors and theoretically to increase the frequency of shock wave emissions, the actual treatment time could be shortened.

The study data were taken from 11 patients treated with ESWL. Two - dimensional ultrasound videos were collected using a video collector, and 5 - minute sequences were randomly selected and labeled. One observer annotated 23,212 frames to determine if the stones were in the FZ, and another generated binary masks of kidneys and stones for 57 images. 11 models (9 trained, 1 validated) were created through patient - cross - validation, and 8 models were tested on 23,212 frames of images from 8 patients to reduce the risk of overfitting. The study was licensed by the regional ethics committee to ensure data compliance, and it also conducted a comprehensive statistical analysis of the data and calculated multiple assessment metrics.

In summary, AI (U - Net neural network) - assisted ESWL improved treatment outcomes. Although there is room for improvement in performance metrics, it made treatment more precise and safer overall.

AI model integrates multiple algorithms and data, extracts 100 radiomics features with the PyRadiomics tool, and extracts 256 autoencoder features with 3D autoencoders [9]. The model was trained using machine learning algorithms such as Support Vector Machine (SVM), Random Forest (RF), XGBoost (XGB), and CatBoost (CB). The data were derived from 317 patients with ureteral calculi collected from October 2023 to March 2024, including basic patient information, CT image data, and the patients were followed up with KUB X-ray examination for 4 weeks after surgery to evaluate the stone clearance. In terms of assisting ESWL, the AI model automatically identified and segmented the regions of ureteral calculi through the analysis of CT images and extracted relevant features to predict the therapeutic effect of ESWL, that is, to determine whether the calculi were cleared or whether the residual fragments were ≤ 2 mm. In terms of performance, the semantic segmentation model achieved an average Dice coefficient of 0.88 ± 0.08 on the external test set. On the internal validation set, the AUROC values of the ESWL classifiers constructed by SVM, RF, XB, and CB were 0.78, 0.84, 0.85, and 0.90, respectively, and on the external test set were 0.68, 0.79, 0.80, and 0.83, respectively, with the CB algorithm performing the best. The advantages of this AI model lie in its innovative integration of advanced imaging analysis techniques, multi-center validation for enhanced robustness and generalization ability of the model, evaluation of multiple machine learning algorithms to determine the optimal algorithm, and enhanced interpretability of model decisions by calculating SHAP values, which can provide reliable decision support for clinical practice. It helps improve treatment outcomes for patients.

3.2 Percutaneous Nephrolithotomy (PCNL)

PCNL is an important surgical method for treating urinary calculi, especially kidney calculi, and plays a key role in the surgical treatment of urinary calculi. Up to now, AI has been used to predict the outcome of PCNL. Aminsharifi et al. included all adult patients who received PCNL at the hospital during the study, recorded preoperative and postoperative variables, and evaluated the perioperative stone-free status by computed tomography [10]. The network was designed and trained with a feedforward backpropagation error adjustment scheme. The preoperative and postoperative data of 200 patients were used as the training set to analyze the influence and relative correlation of preoperative values on postoperative parameters. The trained and validated ANN system was used to predict the postoperative results of 254 adult patients (test set), and the predicted values were compared with the actual results to evaluate the accuracy of the system in predicting each postoperative variable. The test set included 254 patients, 61% of whom were male, with an average stone load of 6702.86±381.6 mm^3, an overall stone-free rate of 76.4%, and 21.3% of patients requiring assisted surgery. The accuracy and sensitivity of the ANN system in predicting different postoperative variables ranged from 81.0% to 98.2%. It demonstrated the system's significant role in predicting postoperative outcomes for PCNL.

Anastasiadis et al. also summarized in the article that PCNL was assisted in multiple aspects such as puncture guidance, surgical planning, postoperative outcome prediction, and intraoperative tissue monitoring, which improved the accuracy, safety, and therapeutic effect of the surgery [11]. Robot-assisted fluoroscopic-guided puncture, for example, not only has a high success rate but also shortens the puncture time and the total duration of the operation. A method of guided PCNL puncture based on AI and optical coherence tomography (OCT) can be developed. By constructing and training the DL algorithm, the OCT patterns of the renal cortex, medulla, and calyces can be identified with high precision, effectively guiding the puncture needle and identifying the type of anterior tissue.

Gauhar et al. explored the application of AI and robotics in PCNL [12]. In terms of algorithms and data, the specific algorithms used by the AI models were not specified in the paper, and the data came from 12 in vivo studies covering patients with different types of nephrolithiasis and related surgical information. In terms of assisting surgery, the 3D reconstruction model uses CT image data for processing to assist in determining the puncture point and designing the puncture path. Robot-assisted systems such as ANT-X use AI to detect marker balls to calculate puncture trajectories. In terms of effectiveness, multiple studies have shown that the use of related technologies can reduce operation time, decrease the number of punctures, increase the success rate of the first puncture and stone clearance, and reduce intraoperative blood loss and complication rates. The advantage lies in enhancing doctors' spatial understanding of the anatomy of the kidneys and improving the precision of preoperative planning and intraoperative operations. 3D printing, virtual, and mixed reality technologies provide doctors with a better training experience and help shorten the learning curve. Robot-assisted techniques can improve puncture accuracy, reduce radiation exposure, and have the potential for remote operation, promising better outcomes for complex and challenging surgeries.

3.3 Ureteroscopic Lithotripsy (URL) And Ureteroscopic Lithotripsy (URS)

URL and URS are essential techniques in the field of endovascular urology. They represent the trend of urological surgery towards minimally invasive and precision, providing doctors with an efficient and safe way to treat stones, as well as patients with better treatment outcomes and less trauma, and promoting the advancement of urological stone treatment techniques. The addition of AI has further promoted this development.

Nedbal et al. employed 16 machine learning algorithms in their study, including logistic regression, quadratic discriminant analysis, and extreme gradient boosting (XGBoost) [13]. The data used were from a cohort of adult patients who underwent ureteroscopic laser lithotripsy (URSL) for urolithiasis between March 2012 and December 2018, covering eight core parameters including preoperative age, gender, and urine culture results. AI-assisted URSL is reflected in the automatic prediction of postoperative outcomes based on preoperative features, such as the use of ureteral access sheath (UAS), postoperative stent insertion, complications, and stone-free status (SFS), through trained models. In predicting SFS, the integrated ML model achieved an accuracy of 93% and a precision of 87%. It also had high accuracy in predicting complications. Its advantage lies in being able to handle complex and multi-faceted datasets, generating personalized risk assessments by integrating patients' demographic and preoperative characteristics, helping clinicians identify high-risk patients, develop preoperative plans, adjust postoperative care programs, and optimize resource allocation, assisting doctors in making wiser decisions and improving patient safety.

In flexible ureteroscopic lithotripsy (fURL) for ureteral calculi, the AI model combined the LASSO algorithm and the deep neural network (DNN) model [14]. The model was constructed based on preoperative non-enhanced CT scan data and related clinical information (such as age, gender and BMI) of 847 patients with unilateral, isolated proximal ureteral calculi, and externally validated with data from 40 patients. Data dimension reduction and feature selection were performed using the LASSO algorithm to determine 26 key predictors and construct radiomics models. The DNN model, based on the extracted features, further improves the prediction accuracy by learning complex relationships through multiple layers of nonlinear activation functions. AI-assisted surgery is reflected in predicting the risk of sepsis after fURL or PCNL before surgery, helping doctors identify high-risk patients and take preventive and monitoring measures in advance. In terms of effectiveness, the LASSO model had an AUC of 0.881 (internal validation) and 0.783 (external validation) for predicting sepsis, while the DNN model had an AUC of 0.920 for internal validation and 0.874 for external validation, demonstrating good predictive capabilities. The advantage of this AI model lies in its ability to make more effective use of information on the characteristics of stones in vivo compared to traditional clinical variables and laboratory tests. DNN models are more predictive than LASSO models and can capture higher-order interactions among variables. It can also facilitate the stratification of sepsis risk in patients and provide strong support for clinical decision-making, though the study has limitations, such as a limited sample size and not including some clinical factors.

AI also plays a key role in stone detection and localization. Through deep learning training on medical imaging data such as CT, MRI, and ultrasound of a large number of patients, AI models such as convolutional neural networks (CNNS) can precisely identify the location, size, shape, and quantity of stones. When processing CT images, the AI algorithm can quickly analyze the features of pixels in the images, distinguish the stones from the surrounding tissues, automatically mark the location of the stones, greatly improve the efficiency and accuracy of detection, reduce the risk of human error, avoid missed diagnosis of stones due to subjective factors of doctors, and help doctors develop a more complete URS surgical plan before surgery.

During URS surgery, the intelligent robot-assisted system uses AI to achieve precise control of instrument operation. The robotic arm was able to move and position the surgical instrument precisely based on the stone location and surrounding tissue information generated by AI analysis of the images. Compared with traditional manual operation, robotic assistance can control operation accuracy to the millimeter level, reduce damage to surrounding tissues such as the ureteral wall, and lower the risk of complications such as intraoperative bleeding and ureteral perforation, especially when dealing with stones in complex locations.

In addition, another major contribution of AI in URS is the realization of real-time assessment and decision support for surgical risks. By integrating multiple sources of information, such as real-time vital sign data of patients, intraoperative images, and instrument operation data, the AI model can dynamically assess surgical risks. In the event of risks such as excessive pressure in the renal pelvis and increased bleeding tendency, the system quickly analyzes and provides response suggestions for the doctor, such as adjusting the flow rate of perfusion fluid, suspending the operation for hemostasis treatment, helping the doctor to optimize the operation plan in time during the operation, ensuring the smooth progress of the operation and improving the overall safety and quality of the operation.

In URS and URL, AI plays a key role with multiple algorithms. When predicting the risk of sepsis, the LASSO algorithm selects key features and works with the DNN model to estimate the risk of sepsis after FURL or PCNL based on preoperative non-enhanced CT and clinical information. The DNN model can capture complex variable relationships to support clinical decisions. In terms of medical imaging, CNNS deeply learn CT, MRI, and ultrasound images to accurately identify the location and size of stones, avoid missed diagnoses, and assist in planning URS surgical pathways. During the operation, AI integrates the patient's vital signs, intraoperative images, and instrument operation data to monitor risks in real time and provide response strategies in case of excessive stress or bleeding risks. At the same time, AI controls the intelligent robot-assisted system to precisely operate the robotic arm, reduce tissue damage, and improve the safety and quality of the surgery.

4 THE ROLE OF AI IN PREVENTION

AI plays a crucial role in the prevention of urinary calculi and helps doctors develop personalized prevention plans for people at high risk, such as reminding them to increase water intake, adjust their diet, and increase physical activity. AI can monitor health data in real time through smart devices or health management platforms, issue risk warnings promptly, and encourage people to actively adjust their lifestyles, thereby effectively reducing the incidence of urinary tract stones and improving public health.

For instance, the AI model developed by Sánchez et al., which uses a variety of machine learning algorithms and has a wide range of data sources that have been strictly screened, has played a key role in predicting the risk of urinary calculi and achieved relatively significant results [15]. They designed questionnaires covering various aspects such as demographics, nutrition, exercise, and medical history, and after pre-trials, they distributed them widely through social media, ultimately collecting 976 valid questionnaires to provide data for the model construction. A variety of classifiers, including logistic regression, decision tree, random forest, and extreme random tree, were used to build the model. Python was programmed in the local computing environment to detect complex patterns that distinguish kidney stone patients from non-patients through pattern recognition and classification, and the classification accuracy was verified based on independent datasets. Statistical methods were used to calculate odds ratios, confidence intervals, and P-values to improve the interpretability of the model, and key variables such as gender, physical activity, and thirst level were selected to refine the model.

The role of AI is mainly to predict the risk of urinary calculi, helping patients and doctors understand the likelihood of getting the disease in advance and then take targeted preventive measures. The AI Model achieved an accuracy rate of 88% in predicting the risk of urinary calculi, demonstrating good discrimination ability, effectively identifying the risk of illness, providing a basis for personalized medical intervention, and promoting the development of precision medicine.

5 THE ROLE OF AI IN POSTOPERATIVE MANAGEMENT AND FOLLOW-UP

In the postoperative management and follow-up stage of urinary calculi surgery, AI is demonstrating unique and crucial value. In terms of complication prediction, AI can integrate multi-source data such as surgical details, postoperative vital signs, and test indicators of patients to build precise prediction models. By learning from a large amount of case data, AI can keenly capture the subtle features associated with complications and detect potential risks in advance. In terms of postoperative assessment and rehabilitation guidance, Hameed et al. mentioned that AI can assess postoperative patients and predict the risk of stone residue and recurrence [16]. By analyzing postoperative images and clinical data, it can be determined whether the stones have been completely removed. Combining the patient's lifestyle and genetic factors, doctors can predict the possibility of stone recurrence, develop personalized rehabilitation plans, and preventive measures for the patient to improve the patient's quality of life and reduce the recurrence rate. In follow-up management, AI uses natural language processing technology to efficiently analyze patient feedback, accurately identify potential problems, and promptly notify doctors to handle them. Through in-depth mining of patients' historical data, AI can predict the risk of stone recurrence and provide targeted preventive measures for patients, such as adjusting lifestyle and regular follow-up suggestions. The use of AI-assisted follow-up management can significantly increase the early detection rate of stone recurrence, improve patient prognosis, enhance patient satisfaction with follow-up, and optimize the overall quality of medical services.

6 DISCUSSION AND PROSPECTS ON AI-ASSISTED MINIMALLY INVASIVE SURGERY FOR URINARY CALCULI

AI-assisted minimally invasive surgery for urinary calculi shows significant advantages in many aspects. In preoperative diagnosis, AI can precisely predict the composition of stones, which is more convenient and accurate than traditional methods, providing a key basis for personalized treatment. When assessing the size and location of stones, AI measurements are more precise and efficient than manual ones, improving diagnostic accuracy and surgical planning. In terms of analyzing treatment strategies, AI uses deep learning to interpret images to help doctors choose the best options and reduce the risk of postoperative complications.

During the procedure, AI plays a significant role in various minimally invasive surgical approaches. In SWL, AI can predict treatment outcomes, precisely focus on stones, and improve the effectiveness and safety of lithotripsy. In PCNL, AI can predict postoperative outcomes, assist in puncture guidance and surgical planning, and improve surgical accuracy and safety. In URL and URS, AI can not only predict postoperative conditions and assess the risk of sepsis, but also precisely detect and locate stones, control robot-assisted operations, and assess surgical risks in real time, improving surgical quality in all aspects. In addition, AI performs well in prevention, postoperative management, and follow-up, predicting stone risk, developing personalized prevention plans, predicting complications and stone recurrence, and optimizing medical services. The commonly used models for AI-assisted minimally invasive surgery in the treatment of urinary tract stones are as follows (Figure 1).

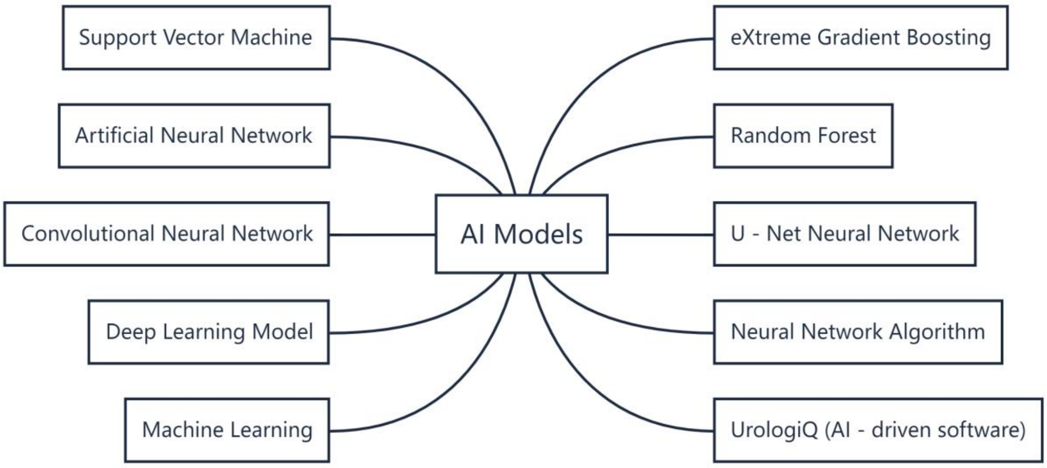

Figure 1 AI Models

However, AI-assisted minimally invasive surgery for urinary calculi also faces many challenges and shortcomings. Technically, the accuracy and stability of some AI models still need to be improved, and different algorithms and data processing methods can affect the prediction and diagnosis results. The quality of the data is uneven, and problems such as incomplete data and inaccurate annotations limit the improvement of model performance. In terms of clinical application, the lack of unified standards and norms for the clinical application of AI technology has led to significant differences in the AI systems used by different medical institutions, making it difficult to popularize them. Doctors have varying levels of familiarity and mastery of AI technology, and some doctors are overly dependent on or reluctant to use AI, which affects the effective application of the technology. At the same time, the high cost of AI technology is also an obstacle to its promotion, including research and development, equipment purchases, and maintenance costs, which increase the financial burden on patients.

For the future, AI-assisted minimally invasive surgery for urinary calculi has great potential. In terms of technology development, algorithms should be further optimized and multimodal data integrated to improve the accuracy, stability, and generalization ability of the model. Strengthen data governance and build high-quality medical imaging and clinical databases to provide reliable data for AI training. In terms of clinical application, unified industry standards and norms need to be established as soon as possible to ensure the safety and effectiveness of AI systems. Strengthen the training of doctors to enhance their ability to apply AI technology and promote the deep integration of AI with clinical practice. From the perspective of cost control, we can reduce costs through technological innovation and large-scale application to improve the cost-effectiveness of AI technology. In addition, enhance international cooperation and exchanges to jointly promote the development of AI-assisted minimally invasive surgery for urinary calculi, provide more efficient and safe treatment options for patients worldwide, and enable AI technology to play a greater role in the field of urinary calculi treatment.

7 CONCLUSIONS

To sum up, AI has shown great potential and value in minimally invasive treatment of urinary calculi. From preoperative diagnosis, surgical procedure, prevention to postoperative management and follow-up, AI technology has played a significant role in all aspects, bringing new ideas and methods to the treatment of urinary calculi. By precisely predicting the composition, size, location, and treatment strategy of the stones, AI helps doctors develop more targeted and personalized treatment plans, improving treatment outcomes and reducing the risk of postoperative complications. During the procedure, the application of AI makes minimally invasive surgeries such as shock wave lithotripsy, percutaneous nephrolithotripsy, ureteroscopic lithotripsy, and ureteroscopic lithotripsy more precise and safer. In the prevention stage, AI helps to develop personalized prevention plans for high-risk groups and reduce the risk of urinary calculi. In postoperative management and follow-up, AI can effectively predict complications and the risk of stone recurrence, provide personalized rehabilitation plans and preventive measures for patients, and improve the overall quality of medical services. Although AI-assisted minimally invasive surgery for urinary calculi still faces challenges in terms of technology and clinical application, these problems are expected to be gradually addressed with the continuous development and improvement of the technology. Through measures such as further optimizing algorithms, strengthening data governance, establishing unified industry standards, enhancing doctors' ability to apply AI technology, and reducing costs, AI-assisted minimally invasive surgery for urinary calculi will be more widely applied in clinical practice, bringing better treatment experience and prognosis to patients with urinary calculi worldwide. To drive continuous progress in the field of urinary calculi treatment.

COMPETING INTERESTS

The author has no relevant financial or non-financial interests to disclose.

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