

Modern methods of surgical treatment of staghorn nephrolithiasis

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Abstract

Staghorn nephrolithiasis is a form of urolithiasis characterized by kidney stones formation that partially or completely fills the collecting system. Staghorn nephrolithiasis has a malignant course, accompanied by collecting system retention and impaired renal function. This pathology is a common cause of disability, which is particularly importance in the context of its prevalence among people of working age. The review systematizes the currently relevant data on surgery of staghorn nephrolithiasis, presents methods of surgical treatment, defines the selection options within them, their advantages and disadvantages, indications, contraindications and complications. This information can help in making an informed decision and increase the effectiveness of treatment for patients with that disease. At the moment, there is an arsenal of treatment options for staghorn nephrolithiasis, among them minimally invasive high-tech operations are the most advanced and recognized as the methods of choice. The modernization of existing technologies increases their efficiency and safety, but their high cost and the impossibility of using in some cases often make one prefer more traumatic radical interventions. Traditional surgery remains a reliable method of treatment, allowing simultaneous operations and treatment of complex cases of the disease. The possibility of combining existing methods allows for the effective removal of staghorn stones in different groups of patients. Thus, a careful and differentiated approach to the methods of surgical treatment of staghorn nephrolithiasis, their use in combination allows ensuring high efficiency of surgical treatment of this pathology.

Keywords: staghorn nephrolithiasis, staghorn stone, urolithiasis, percutaneous nephrolithotripsy, extracorporeal shock wave lithotripsy, retrograde intrarenal surgery, open surgery.

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Staghorn nephrolithiasis (SN) is a severe form of urolithiasis characterized by the formation of kidney stones that fill at least one group of calyces and a pelvis, and accounts for 3–30% of all urolithiasis cases [1,2]. In developed countries, this figure is lower because of the early prevention and treatment of urinary tract infections [3].

The classification of SN by Yanenko and Khurtsev is the most widespread [4] as follows:

- (i) C1—calculus fills the pelvis and one of the calyces;
- (ii) C2—calculus fills the pelvis and at least two calyces (40–60% of the pyelocaliceal system [PCS] volume);
- (iii) C3—calculus occupies 60–80% of the PCS volume;
- (iv) C4—calculus has numerous processes and fills the entire deformed PCS.

The formation of staghorn stones (SSs) is closely related to the infectious process; they are in-

fectured in 49–68% of cases, and 24% of them are struvite [3,5]. They can also consist of uric acid, cystine, and carbonate apatite [6]. Urease-producing bacteria such as *Proteus mirabilis*, *Klebsiella* species, *Providencia rettgeri*, and *Morganella morganii*, which contribute to calculus formation from struvite by increasing urine pH above 7.0, are traditionally considered the main pathogenic microorganisms that initiate SS formation [7].

At the same time, a multicenter study by Parikhomenko et al. demonstrated the identification of traditional urease-producing microorganisms in only half of patients with struvite stones and a positive stone culture. The most frequently detected pathogens were *Enterococcus*, *Proteus*, and *Escherichia coli* [8]. There are also data that show the involvement in lithogenesis of nanobacteria, which become the center of crystallization, and staphylococci with urealytic activity (*Staphylococcus cohnii* sub. *urealyticum*) [7,9].

At present, the number of SSs from calcium phosphate is increasing, which indicates an increase in the etiological role of the metabolic factor [5]. Metabolic disorders are particularly significant in the formation of bilateral SSs [10]. SN is combined with osteoporosis and osteopenia in 22% and 32% of cases, respectively [11]. Urinary tract obstruction, anatomical abnormalities, prolonged urethral catheter installation, ureter plastic surgery, and neurogenic bladder also play a certain role in SS formation [5].

SS often does not cause symptoms and can be detected during routine examination [12,13]. Krzymien et al. recommended considering the possibility of nephrolithiasis in patients with recurrent urinary tract infections [12]. Of patients, 70.2% with SN are admitted in an urgent order, and 66% of them have calculous pyelonephritis exacerbation [14].

The problem of surgical treatment of SN is especially acute because this disease has a malignant nature; SS has a damaging effect on the kidneys through obstruction, recurrent infection, chronic inflammation, and fibrosis [15]. There are reports on the relationship of SN with the development of xanthogranulomatous pyelonephritis [16–18], pyonephrosis [19], malignant transformation of the urothelium [20,21], and its possible complication with urinoma [22]. The affected kidney becomes hypervascularized, which increases the risk of bleeding and infection during surgery [23]. In SN, chronic kidney disease is much more common and has more serious consequences [7].

According to Shormanova et al., SN becomes the third most common indication for nephrectomy [24]. Because the presence of SS leads to deterioration of kidney function and its death, the American Urological Association recommends the complete removal of SS [16]. The methods used in SN surgery include currently extracorporeal lithotripsy, contact lithotripsy with different options, and traditional surgery.

In the case of SN, extracorporeal shock wave lithotripsy (ESWL) can be performed as monotherapy or adjunct. In view of the lowest injury rate, ESWL is considered the treatment standard for stones smaller than 20 mm. For large stones, ESWL is traditionally considered an adjunct because, as monotherapy, it has low efficacy, high complication rate (71.49%), and high additional intervention needs (85.71%) [5,25,26]. After ESWL monotherapy of SN, complications such as an attack of renal colic, development of acute pyelonephritis and urosepsis, and formation of a steinstrasse and perirenal hematoma develop [5,26].

However, Benoit Vogt et al. managed to expand the indications of ESWL monotherapy in SN

by developing the MiniJFil stent in 2016 [25]. The stone-free rate (SFR) was 75%; therefore, the authors considered ESWL to be a first-line treatment method, but this study was conducted with a limited number of patients [25,27]. When analyzing the questionnaires of the quality of life, Berestetsky et al. concluded that after ESWL of SS, clinical and labor rehabilitation occurs earlier than percutaneous nephrolithotripsy (PNL) [28].

According to the guidelines of the American Urological Association and the European Association of Urology, PNL is the gold standard for the removal of stones larger than 20 mm in diameter [29]. SFR after PNL monotherapy in SN is 94.37% [26]. The average duration of the intervention, according to Rogachikov et al., is 71.61 ± 18.65 min. It is reliably associated with only two parameters—the size and density of the calculus [30]. This technology continues to evolve, the SFR increases, and the duration of hospital stay and surgery time decreases [31].

PNL significantly improved the quality of life of patients in the next 6 months, even in the presence of residual fragments and recurrence of nephrolithiasis and increases their physical, social activity, and psychological state [32]. PNL is effectively used in patients with developmental abnormalities of the kidneys and skeleton; it can be recommended as a first-line method with a large stone load in the horseshoe kidney [33,34]. With a proper approach, PNL is an effective method in patients of all ages; however, in patients over 65 years of age, an increased blood transfusion need is noted [35,36].

Stone size is directly related to a decrease in PNL efficacy. Thus, in the presence of a stone larger than 45 mm in a solitary kidney, the PNL efficacy decreases by 4.6 times [37,38]. Overweight also reduces the efficacy of PNL. In obese patients, the surgical technique should be accompanied by accurate patient positioning, long and flexible instrument use, shortest approach, and adequate drainage [38–40].

Among the factors influencing the efficacy and safety of PNL, Yanenko et al. distinguished the size, density, composition, and type of the calculus (staghorn or large), type of lithotripter, diameter of the nephroscope tube, use of the casing for the nephroscope, and number of approaches. According to the authors, SS itself is associated with a lower efficiency of PNL, and the most effective lithotripter is ultrasonic [41].

The incidence of complications in PNL is 8.75%, and the most frequent of which are bleeding and infectious complications; injuries of the urinary tract and adjacent organs are noted less often [26,42]. There are several reports on the possi-

bility of nephropleural fistula development in the late postoperative period [43,44]. SSs themselves represent a risk factor for developing intraoperative and postoperative complications [45–47]. Long and rough manipulations in the kidney, performed in cases of large stones, often lead to renal vessel injuries, which increase blood loss risks and blood transfusion needs [48].

Removal of SSs is a laborious process with a longer duration of the surgery and a higher frequency of leaving residual fragments [49,50]. SSs are associated with a higher incidence of postoperative infectious complications, increasing this indicator by more than three times, which is associated with more frequent use of multiple approach, greater need for blood transfusion, removal of incomplete calculus, and longer duration of surgery [51–55].

The development of infectious complications after PNL is also influenced by the presence of diabetes mellitus, renal failure, and hydronephrosis in a patient [56–58]. To prevent severe infectious complications, treatment should be performed in several stages and avoid surgeries longer than 120 min [59]. Compared with open surgeries in PNL, there is a decrease in such indicators as postoperative complication incidence, surgical time, hospitalization duration, blood loss volume, and blood transfusion needs. However, the SFR after the first PNL session is significantly lower than after open surgery, and the result depends greatly on the calculus composition [60]. Despite several advantages, classical PNL remains the most traumatic treatment for SN after open surgery [61].

The management issues facing surgeons during PNL relate to the choice of the patient's position, analgesia method, PCS approach, navigation method, instrumentation choices, drainage method, and residual fragment removal method, which is influenced by the anatomy of the PCS, size, composition, and location of the calculus, and presence of obstruction below the stone [62]. PNL is traditionally performed in a prone position, which provides a larger surface area for choosing a puncture site, wider field for manipulating instruments, and lower risk of damage to adjacent organs [61,62].

Mazurenko et al. considered surgeries in the supine position to be indicated to patients with respiratory failure and forced position (e.g., with ankylosing spondylitis) [62]. Rogachikov et al. noted that the use of the supine position reduces the time of patient placement and creates difficulties in manipulation with instruments. Also, the supine position assumes the position of the instrument with an inclination downward, which facilitates the spontaneous migration of fragments [1]. There are many other options for patient position-

ing during PNL, but there is not enough research to confirm their effectiveness [61].

In patients with a high anesthetic risk, PNL can be performed effectively and safely under epidural, spinal, and even local infiltration anesthesia [63–67]. Buldu et al., having compared the use of spinal anesthesia with total intravenous anesthesia during PNL of SS in similar groups, revealed its efficiency and safety [64]. In a study by Atmoko et al., 81.4% of all PNLs of SS were performed under spinal anesthesia. SFR and surgical time were similar to those with general anesthesia [65].

Nouralizadeh et al. also revealed that in young patients (43 ± 13 years) and patients with large stones, lower efficacy (SFR 61.9%) and safety rates were noted during PNL under spinal anesthesia [66]. Ecke et al. presented 114 PNLs of SS cases performed under local anesthesia, and in 68.4% of cases, the patients required additional anesthesia [67]. With SN, there was an increased need for additional percutaneous approach and more than one stage of PNL [2,5,49,68]. The use of multiple approaches significantly increased the efficiency of surgery and decreased the number of residual fragments, but it increased the duration, hospital stay, radiation exposure, and complication rate [37,62, 69–71].

Zhao et al. analyzed the results of two-stage PNL variants and found a significantly lower number of approaches, infectious complications, and blood transfusion needs [72]. This is especially true if the patient has a solitary kidney, which in itself is associated with a higher incidence of complications after PNL [73,74].

If multiple approaches are initially planned, Ding et al. recommended making a second approach in advance, since this approach reduces surgical time and blood transfusion frequency [75]. The removal of a large SS (10 cm) through one approach in one session, with a surgical duration of 3 h, was reported [76].

Xiao et al. revealed that the width of the calyx neck is a factor predicting the effectiveness of PNL and the need for multiple approaches [77]. In PNL, it is preferable to create a puncture passage through the posterior group of calyces as the least vascularized zone [62]. Traditionally, the approach through the upper calyx in the prone position is more appropriate for removing SS [78]. PNL, performed through the upper calyx, provides direct approach to all elements of the PCS and the upper part of the ureter, ensuring maximum stone removal [42, 69,79]. At the same time, the creation of approach through the upper pole is associated with an increased risk of complications, especially trauma to the intrathoracic organs and hemorrhage [42,69, 80].

PNL through the lower pole is associated with fewer complications and lower SFR [29]. However, Tan et al. revealed that providing approach through the lower pole is a risk factor for severe bleeding, which is associated with abundant vascularization of the parenchyma of the lower pole, the need for an oblique and long approach, and a smaller size of the lower calyx, and therefore, the authors recommended approaching through the middle calyx [81].

Yan et al. recommended performing a puncture over rib XII when approaching through the middle or upper calyx to prevent bleeding. The authors noted that the puncture angle is straighter, and the chance to damage the interlobar vessels is lower [42]. With subcostal puncture, there is a risk of damage to the subcostal nerve with further loss of muscle tone in the abdominal wall [82]. To avoid injury to the pleura, when approaching through the superior calyx, puncture should be performed lateral to the middle of rib XII [42].

Puncture control during PNL is based on ultrasound and fluoroscopic methods, and navigation with computed or magnetic resonance imaging is used less often [1]. The fluoroscopic method is more widespread, but its use is associated with a higher frequency of damage to adjacent organs and increased radiation exposure [61,83]. Kim recommended focusing initially on the selected calyx fluoroscopically and performing the puncture itself under ultrasound guidance. In his opinion, navigation using computed tomography is advisable to use in case of hard-to-reach calyces or the presence of skeletal anomalies, such as scoliosis or *spina bifida*. Navigation using magnetic resonance imaging avoids the effects of ionizing radiation, although it is inferior in the visualization of instrumentation [61].

SSs occupy a large part of the collecting system of the kidney, and therefore, the use of ultrasound control alone can cause difficulties [84]. According to Yanenko et al., ultrasonic lithotripter is 2.2 times more effective and 2.7 times safer than other devices [41]. In a study by El-Nahas et al., an increase in surgical duration was noted with the use of a holmium laser compared with an ultrasonic one [85]. At the same time, Mazurenko et al. indicated that an increase in the surgical duration when using a laser lithotripter does not increase radiation exposure and complication incidence [86].

Tedorovich et al. noted the slow rate of calculus destruction with HO:YAG laser lithotripter, indicating the possibility of using the Russian laser surgical complex Lazurit, which could fragment calculi at a much higher rate than holmium analogous devices [87]. According to Mazurenko et al.,

when crushing stones with a density higher than 1200 Hu, the use of an ultrasonic lithotripter is often ineffective.

Considering the pneumatic lithotripsy option, the authors drew attention to the presence of counterpulsion (displacement of the stone during crushing), which increases the probability of bleeding and perforation of the PCS [86]. Also, pneumatic lithotripters have limited or no absorptive function, and therefore, a combined lithotripter Swiss Litho-Clast Ultra were created to combine the characteristics of both methods [61]. Since traditional PNL involves the use of tools with a diameter of 24 Ch, more instruments of a smaller diameter have been introduced into practice to reduce surgical trauma [37,61]. Currently, there are classic (24–26 Ch), miniaturized (15–18 Ch), ultramini (11–13 Ch), and microvariants (4.85 Ch) options.

According to de Fata-Chillón, classic and mini-variants are equally effective (80% SFR after 3 months) and safe [88]. Arustamov et al., in turn, reported that for a solitary kidney, the use of nephroscopes less than 24 Ch in diameter is 3.6 times safer than using instruments larger than 24 Ch [37]. The PCS anatomy is the fundamental factor that determines the possibility and feasibility of using minimally invasive technologies [30].

Ganpule et al. recommended considering the stone size when choosing the PNL type, with mini-PNL used for 1.5–2 cm calculi and ultramini-PNL and micro-PNL for smaller than 1.5 cm stones [89]. The disadvantage of mini-PNL consists of the impossibility to use ultrasonic lithotripters since the probes designed for use with a nephroscope are too wide and small-diameter probes are clogged quickly with the resulting sand [87]. Mini-technologies reduce the risks of complications, especially hemorrhagic ones, but increase surgical duration because of the need for finer fragmentation of the stone and the time of their extraction through a small-diameter tube, despite the Bernoulli phenomenon [1,90].

With the standard technique, the stage of approach formation takes longer than with mini-PNL, and the stages of fragmentation and extraction are shorter [30]. For PNL, rigid, semi-rigid, and flexible instrumentation can be used. Semi-rigid instrumentation provides more efficient removal of SS compared with rigid ones and enables achievement of a high SFR through a single approach [91, 92]. The use of flexible tools, as noted by Xiao et al., is a laborious and time-consuming process [92]. At the same time, mini-PNL with the use of flexible instruments in combination with retrograde intervention can effectively remove stones from the patient through a single approach, reduce compli-

cation incidence, and shorten the surgical time and hospital stay duration [93].

The approach can be performed in one step or with progressive bougienage. The use of the one step approach method, although it is safer and shorter, is undesirable in SN, since it is often impossible to advance the outer casing to the lumen of the calyx [1]. El-Shazly et al. compared the efficiency of balloon dilation and dilatation with telescopic metal bougies in the case of SS and reported the advantage of the latter [94].

Nephrostomy is placed after PNL to ensure hemostasis, adequate drainage, and subsequent intervention and contrast antegrade study approaches [1]. The presence of a nephrostomy is associated with pain in the postoperative period and longer hospitalization [42,61]. In 1997, tubeless PNL (without nephrostomy) was introduced, but later, when examining the results of studies in similar groups, it turned out that it does not have any advantages and, moreover, is associated with many infectious complications in the postoperative period [95]. In multicenter studies, the criteria for the possibility of using tubeless PNL have been determined, namely, the absence of urinary tract infection, use of less than two ports during surgery, calculus size of less than 3 cm, surgical duration of less than 2 h, absence of complications, complete removal of the calculus, and absence of obstruction [1].

To prevent bleeding in the absence of a nephrostomy, various techniques have been developed, which remain controversial and not widespread. These include electrocoagulating, suturing the fistulous tract, and using fibrin adhesive and hemostatic drugs [1]. In tubeless PNL, an internal stent is placed, which in turn can cause symptoms of damage to the lower urinary tract and vesico-ureteral reflux. To avoid this, a tubeless PNL has been proposed that does not involve postoperative drainage. Its efficiency and safety have been proven in certain groups of patients [61].

There is a mini-drainage technique using a small-diameter nephrostome (10–12 Ch), which shortens the time of percutaneous drainage (up to 1 day) [1,30]. SFR after the first PNL session of SS is low and amounts to 62.6% [65].

Nasirov et al. noted that the presence of residual fragments after PNL is most commonly caused by inaccessibility of the calyx for the endoscope and intraoperative bleeding [96]. To remove residual fragments, ESWL (sandwich therapy), repeated PNL through the existing passage (second-look PNL), repeated PNL with a new approach, retrograde intrarenal surgery (RIRS), drug therapy, and case follow-up can be used.

Previously, “sandwich” therapy was actively used; however, nowadays, the endoscopic methods of treatment demonstrate higher efficiency and economic feasibility [97]. Second-look PNL can be used in cases where PNL was interrupted (due to bleeding, perforation, and long surgical duration) or as a second stage of treatment with a large stone load. It has a rate of complications equivalent to primary PNL but is associated with an increased hospital stay duration, pain relief and antibiotic needs, and higher treatment cost [98].

Repeated PNL with the creation of a new approach is used when PNL is not reasonable through several approaches (in cases of renal failure, solitary kidney, and infectious stones) [99]. RIRS is more effective than ESWL in removing residual fragments, but the high cost and need for endotracheal anesthesia are becoming limiting factors [99].

Drug therapy, involving the use of citrate mixtures and diet correction, is used mainly in case of urate stones. With SN, antibiotic therapy is always prescribed to patients after surgery, which is also a method for preventing recurrent stone formation [97].

Chemolysis of residual fragments can be performed through a nephrostomy drainage using Suby G solution and renacidin. At the same time, to avoid infectious complications and electrolyte imbalance, it is necessary to minimize intrarenal pressure, achieve sterile urine, measure phosphate and magnesium blood levels, and conduct antibiotic therapy before, during, and after percutaneous chemolysis [5].

Patients who have no symptoms or proven urinary tract infection, and with fragments smaller than 4 mm, can be actively monitored [100].

For successful PNL, an understanding of the PCS anatomy is required. Modern modeling technologies based on computed and magnetic resonance imaging data provide not only PCS visualization but also training opportunities for the surgeon. Numerous studies have shown their effect on improving treatment outcomes and prevention of intraoperative and postoperative complications [101–107]. There are many scoring systems that predict the efficiency of PNL, in which, only the STONE nomogram can predict SFR in relation to SN [47, 108]. However, not a single scoring system is effective for predicting complications [109–111].

The use of RIRS in SN is possible both as monotherapy and in combination with other methods. Amosov et al. recommended retrograde nephrolithotripsy monotherapy as an alternative method at stages C1–C2, since it can be performed without injuring the renal parenchyma and reducing kidney function at these stages [112]. According to a study

by Park et al., the greatest effectiveness of RIRS monotherapy is achieved with a maximum stone diameter of 19.1 mm and a volume of 15,000 mm³, which is comparable with mini-PNL. However, in the case of large stones (>21.6 mm), SFR after RIRS is lower, and in this case, mini-PNL should be preferred [61,113].

Vaidyanathan et al. recommended performing RIRS under low pressure to avoid subcapsular hematoma formation and surgical time prolongation [114]. With active irrigation during RIRS, intrarenal pressure values can exceed the norm by several times, causing pyelovenous, pyelotubular, and pyelolymphatic refluxes and parenchymal damage, which can affect renal function and cause infectious complications [30].

RIRS has relative contraindications, including extended strictures and urethral obliteration, ureterocystoanastomosis in history, prostate adenoma with pronounced intravesical growth, chronic prostatitis or orchiepididymitis, fixed ureter deviations after inflammatory diseases, and surgical history on the retroperitoneal organs [115]. According to several studies, the combined use of RIRS with PNL or mini-PNL compared with PNL monotherapy has a significantly higher SFR after the first procedure, avoids the use of multiple approaches, shortens the time of surgery, and reduces the risk of intraoperative complications [61,112,116–120]. Also, this combination can be used to effectively remove SS from a horseshoe or solitary functioning kidney [121,122].

To prepare the ureter for ureteroscopy sheath insertion, Benoit Vogt et al. recommended the use of the MiniJFil stent, which enables the insertion of an endoscope of a larger diameter (11 Ch) to remove large stones. In this way, the authors managed to achieve complete elimination of SS in 75% of cases [25,123]. Schults et al. reported a case of SS removal with a diameter of 3 cm in a child using ESWL and subsequent RIRS. The authors attributed the successful outcome to the low density of struvite stones and large ratio of targeting volume to the patient size [124].

Traditional SN surgery involves the greatest trauma to the kidney tissue. It includes open, laparoscopic, and robot-assisted surgeries. In clinical centers that have equipment for performing less invasive surgeries and have accumulated knowledge and experience in treating nephrolithiasis, the need for open surgery amounts to 1–5.4% [1]. At the same time, in general, indications for open surgical interventions in SN occur in 55% of cases [26]. In summary, they include contraindications for less invasive surgeries, previous unsuccessful endourological intervention, large SS (>2500 mm²), significant ectasia of the PCS, and patient's choice [5].

The more invasive the treatment method is and the more severely the kidney function is subsequently affected, the more SFR is after the first session, the lower is the need for additional procedures, and the lower is the total treatment cost [125–127]. Among all types of surgical treatment, open surgical interventions are the longest and, on average, take 118.86 ± 41.77 min [26]. In complex forms of nephrolithiasis, PNL often presupposes additional surgeries, whereas open surgeries achieve complete removal of the calculus in one stage without leaving residual fragments [128–130].

Anatrophic nephrolithotomy, due to the formation of approach through a relatively avascular zone, minimizes damage to the renal parenchyma while ensuring complete stone removal [2,131]. In a study by Lunardi et al., the efficacy of anatrophic nephrolithotomy was 92%, and creatinine clearance was normalized within 3 months, which suggests good results in terms of both stone removal and kidney function preservation [132].

Modified anatrophic nephrolithotomy (with cross-clamping of segmental arteries, without the need for local hypothermia) is simpler and shorter in duration, but with regard to kidney function, the standard option is still more advantageous. Robot-assisted surgeries are effective, but they are not widely used because of their high cost [2,131,133].

Research by Kochkin et al. noted the possibility of an effective laparoscopic anatrophic nephrolithotomy through a transmesenteric approach, which shortens the surgical time because of the absence of the need to mobilize the colon [134]. Glybochko et al. recommended laparoscopic surgeries for treating SN, indicating that percutaneous stone removal is longer than the recommended time intervals and is associated with an increased risk of infectious complications [135].

Laparoscopic surgery can be an alternative to PNL for SSs located in the large extrarenal pelvis. They have higher SFR, fewer complications, and better prognosis for kidney function [136,137]. Laparoscopic surgery can also be used along with retrograde ones, while the kidney is freed from SS in one session without damaging the parenchyma [138,139]. Laparoscopic surgery provides good results in high-risk patients (coronary heart disease and chronic renal failure) and in patients with pelvic dystopia of the kidney [140,141]. The technology of laparoscopic pyelolithotomy is available to many urological hospitals, does not require large financial costs, and like other traditional surgeries, provides the possibility of simultaneous interventions [2,38]. The complications, recorded during open surgeries in 63.63% of cases, include peritoneum opening, bleeding, adjacent organ damage,

wound suppuration, acute pyelonephritis, pneumonia, and granular kidney [26].

Currently, there is a whole range of methods for treating SN, including mini-invasive high-tech surgeries, which are the most advanced and recognized methods of choice. The modernization of existing technologies increases their efficiency and safety; however, because of their high cost and the impossibility of use in some cases, traumatic and radical interventions are often preferable. Traditional surgery remains a reliable treatment method, which includes simultaneous interventions and complex case treatment of this disease. The possibility of combining existing methods enables to remove effectively SSs in different groups of patients. Thus, a careful and differentiated approach to the methods of surgical treatment of SN, and their combined use, ensures high efficiency of surgical treatment of this pathology.

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