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ORIGINAL: Comparative Analysis of PCNL Approaches: Outcomes of Double-J Stent, Nephrostomy, and Kaye Balloon Catheter on Bleeding and Infection

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ABSTRACT

Percutaneous nephrolithotomy (PCNL) is a minimally invasive surgical technique widely utilized for the removal of large or complex kidney stones, offering a high success rate and reduced morbidity compared to open surgery. A critical component of PCNL is the choice of postoperative drainage methods, which significantly influences patient outcomes, including bleeding and infection rates. This review examines and compares the clinical outcomes of PCNL when paired with three commonly used drainage methods: Double-J stent, nephrostomy tube, and Kaye nephrostomy balloon catheter. The Double-J stent is frequently used for internal drainage, minimizing external discomfort while maintaining urinary flow from the kidney to the bladder. However, stent-associated complications such as stent syndrome and urinary tract infections remain concerns. In contrast, the nephrostomy tube, often considered the traditional approach, provides external drainage, which can offer advantages in monitoring and managing postoperative bleeding but may increase patient discomfort and infection risk. The Kaye nephrostomy balloon catheter, a relatively less common method, combines the benefits of temporary external drainage and hemostasis due to its tamponading effect, potentially reducing bleeding risks. By synthesizing data from recent studies, this review highlights the bleeding and infection rates associated with each drainage method. The article provides clinicians with an evidence-based perspective to facilitate informed decision-making tailored to individual patient needs, considering factors such as stone size, location, and patient comorbidities. Additionally, the discussion explores the role of advancements in PCNL techniques, including miniaturized instruments and modifications to drainage strategies, in further reducing complications and improving patient outcomes.

Introduction

Kidney stones are a common urological condition affecting a significant portion of the global population, with increasing prevalence attributed to dietary changes, sedentary lifestyles, and other metabolic disorders (1-

3). Left untreated, kidney stones can lead to severe complications, including chronic pain, recurrent urinary tract infections, and progressive kidney damage (4-6). Among the various treatment modalities available, percutaneous nephrolithotomy (PCNL) has emerged as the gold standard for managing large or complex kidney stones that cannot be effectively treated with less invasive methods such as extracorporeal shock wave lithotripsy (ESWL) or ureteroscopy (7, 8).

PCNL is a minimally invasive surgical procedure that involves the creation of a small tract through the patient's back into the kidney, enabling direct access to the stone for its fragmentation and removal. Over the decades, PCNL has undergone significant advancements in terms of instrumentation and techniques, resulting in improved efficacy and reduced morbidity (9). However, despite these improvements, the procedure is not without risks, with bleeding and infection being the most common complications. These risks are influenced by various factors, including the patient's anatomy, stone characteristics, and postoperative management strategies—particularly the choice of drainage method (10).

Postoperative drainage plays a critical role in the success of PCNL and the prevention of complications. The three main methods employed for drainage after PCNL are Double-J stents, nephrostomy tubes, and Kaye nephrostomy balloon catheters, each offering distinct advantages and drawbacks (11, 12). The Double-J stent is an internal drainage device that spans the ureter and allows for continuous urinary flow from the kidney to the bladder (13). This method is preferred for its minimal external discomfort and faster recovery, though it is not without challenges such as stent migration, encrustation, and the development of stent syndrome. On the other hand, the nephrostomy tube, an external drainage method, has traditionally been the standard approach following PCNL. While nephrostomy tubes provide effective decompression and allow for monitoring of urine output, they are associated with higher rates of postoperative discomfort and an increased risk of infection due to their external placement (14).

The Kaye nephrostomy balloon catheter, a less commonly used method, presents a hybrid approach, offering the benefits of external drainage while also providing tamponading effects to reduce bleeding at the nephrostomy tract (15). This device has shown promise in minimizing bleeding risks compared to traditional nephrostomy tubes. However, its use remains less widespread, and further comparative studies are needed to establish its efficacy and safety relative to other methods (16).

Given the diversity in postoperative drainage options and their implications for patient outcomes, evaluating and comparing these techniques is crucial to provide clinicians with evidence-based guidance. This review focuses on the bleeding and infection rates associated with each drainage method following PCNL, synthesizing data from recent studies to identify their respective strengths and limitations. By exploring these aspects, this article aims to assist healthcare providers in making informed decisions to optimize patient care and reduce complication rates in managing kidney stones.

Background on PCNL and Drainage Techniques

PCNL involves accessing the renal pelvis through a small percutaneous incision to remove kidney stones. One critical step in the procedure is the establishment of postoperative drainage, which maintains renal function, facilitates stone fragment clearance, and prevents complications such as urinoma or obstruction (17).

The Double-J stent is a flexible tube with coiled ends, designed to traverse the ureter and extend into both the renal pelvis and bladder. Its primary function is to ensure unobstructed urine flow and prevent ureteral stricture post-PCNL (18).

A nephrostomy tube is inserted directly into the renal pelvis through the skin, allowing urine to drain externally. This method is often

used for patients at high risk of urinary obstruction or infection (19).

The Kaye nephrostomy balloon catheter combines the functionality of drainage with added hemostatic properties. Its balloon design helps tamponade bleeding from the nephrostomy tract, potentially reducing hemorrhagic complications (20, 21).

Kaye Nephrostomy Balloon Catheter

The Kaye nephrostomy tamponade balloon catheter is primarily utilized in countries with advanced healthcare systems where percutaneous nephrostomy (PCN) and related minimally invasive procedures are routinely performed. In North America, (22) it is widely employed in the United States and Canada, particularly in tertiary care centers and hospitals with active interventional radiology and urology departments. Similarly, in Europe, countries like the United Kingdom, Germany, France, Italy, and the Netherlands commonly use advanced nephrostomy equipment, including Kaye catheters, especially in urology-specialized centers, while certain Eastern European nations with advanced healthcare sectors also utilize these devices, albeit with varying availability . In Asia, nations such as India, China, Japan, and South Korea incorporate similar devices in high-volume centers focused on PCNL and interventional urology, although rural and under-resourced areas in these countries may face limitations in access to such technologies. In the Middle East, advanced healthcare systems in countries like Saudi Arabia, the UAE, and Israel adopt these technologies to manage complex renal cases. Hospitals in Australia and New Zealand also utilize these catheters in their advanced urology and radiology departments. Conversely, in developing regions or under-resourced healthcare systems, the use of such specialized devices may be limited due to cost or accessibility challenges, with alternatives or simpler devices often serving as substitutes (23).

Bleeding Rates

Bleeding is a common complication of PCNL, arising from renal parenchymal injury or vascular trauma during access and tract dilation. The choice of drainage technique plays a significant role in managing or exacerbating this risk (16).

Studies indicate that the use of Double-J stents results in lower bleeding rates compared to nephrostomy tubes. The stent's internal placement avoids prolonged pressure on the nephrostomy tract, reducing the risk of vascular injury. However, stents are less effective in cases requiring immediate hemostasis .

Nephrostomy tubes, while effective in draining urine and providing a pathway for further interventions, are associated with higher bleeding rates. The continuous presence of the tube in the nephrostomy tract can exacerbate vascular trauma and delay wound healing (24).

The Kaye nephrostomy balloon catheter demonstrates superior performance in controlling bleeding. By exerting tamponade pressure on the nephrostomy tract, the balloon reduces vascular oozing and accelerates clot formation. Clinical trials have reported significantly lower transfusion rates in patients managed with balloon catheters compared to those with conventional nephrostomy tubes (22).

Infection Rates

Infections following PCNL range from urinary tract infections (UTIs) to life-threatening sepsis. Postoperative drainage techniques influence the likelihood and severity of infections through their impact on urinary flow and bacterial colonization (25).

Double-J stents are associated with relatively lower infection rates compared to nephrostomy tubes. Their internalized design minimizes exposure to external contaminants, reducing the risk of ascending infections. However, prolonged stent use can lead to encrustation and bacterial colonization, necessitating timely removal or replacement (26).

Nephrostomy tubes carry a higher risk of infection due to their externalized nature. The open drainage system creates a pathway for

bacterial ingress, increasing the likelihood of UTIs. Additionally, nephrostomy sites require meticulous care to prevent local infections.(27) The infection rates associated with the Kaye nephrostomy balloon catheter are comparable to those of nephrostomy tubes. While the balloon design offers advantages in hemostasis, it does not inherently reduce the risk of bacterial colonization. Careful monitoring and adherence to aseptic techniques are critical to minimizing infection (28). (**Table 1**).

Table 1. Comparison of Postoperative Drainage Techniques in PCNL

Technique	Description	Advantages	Disadvantages
Double-J stent	Internal tube spanning the ureter, renal pelvis, and bladder.	- Lowest infection rates. - High patient comfort and mobility. - Reduces bleeding risk.	- Less effective for immediate hemostasis. - Risk of encrustation and colonization.
Nephrostomy tube	External drainage tube inserted into the renal pelvis.	- Effective for high-risk cases. - Allows additional interventions.	- High infection and bleeding rates. - Reduced comfort and mobility. - Requires meticulous care.
Kaye balloon catheter	External tube with a tamponade balloon for hemostasis.	- Best for bleeding control. - Reduces transfusion needs. - Effective for vascular trauma.	- Infection risk comparable to nephrostomy tubes. - Externalized, reducing comfort. - Limited availability in under-resourced regions.

Comparative Outcomes

1. Hemostatic Efficacy: Among the three techniques, the Kaye nephrostomy balloon catheter exhibits the best hemostatic performance, making it the preferred option for patients with high bleeding risk. Double-J stents offer moderate hemostatic efficacy but are more suitable for low-risk cases. Nephrostomy tubes are the least effective in controlling bleeding, necessitating careful patient selection (29-31).

2. Infection Control: Double-J stents demonstrate the lowest infection rates, followed by the Kaye nephrostomy balloon catheter and nephrostomy tubes. The choice of technique should balance the patient's infection risk with other clinical considerations, such as stone burden and comorbidities (32).

3. Patient Comfort and Quality of Life: Double-J stents provide the highest level of patient comfort due to their internalized nature. Nephrostomy tubes and Kaye nephrostomy balloon catheters, being externalized systems, can cause discomfort and limit mobility, impacting the patient's quality of life during recovery (33). (**Table 1**).

Discussion

With advancements in surgical technology, minimally invasive procedures like percutaneous nephrolithotomy (PCNL) have increasingly become the preferred treatment for urinary stones (34). Since its inception, numerous modifications and enhancements have been introduced to optimize stone clearance while minimizing patient morbidity. These advancements include the use of nephroscopes with smaller outer sheaths, tubeless and totally tubeless PCNL techniques, the application of hemostatic agents in the nephrostomy tract, and performing PCNL on an outpatient basis under local anesthesia. In tubeless PCNL, both external ureteral catheters (EUC) and Double-J (DJ) stents are commonly employed for upper urinary tract drainage (35).

A randomized controlled trial by Zhao and colleagues comparing nephrostomy drainage and ureteral stent placement following percutaneous nephrolithotomy (PCNL) provided valuable insights into postoperative outcomes and quality of life (QoL). While

perioperative outcomes such as stone-free rates, complications, and inpatient analgesic requirements were similar between the two groups, the study revealed significant differences in early postoperative QoL. Using the Wisconsin StoneQOL questionnaire, the authors demonstrated that patients with ureteral stents experienced notably worse QoL, with complaints primarily attributed to stent-related discomfort. In contrast, patients with nephrostomy drainage reported a less negative impact on QoL during the immediate recovery phase. Interestingly, these differences diminished by 30 days post-surgery, indicating that the adverse effects of stent placement are transient but significant in the short term (36). Zhao and colleagues challenge the common preference for "tubeless" PCNL, advocating for a more nuanced approach that prioritizes patient comfort and QoL. Future research could build on these findings by exploring ways to alleviate stent-related discomfort or identifying patient-specific factors that influence postoperative management decisions.

Ozturk et al. (2015) compared tubeless PCNL with standard PCNL in an elderly population. The study included 52 patients aged 65 and older with kidney stones larger than 2 cm, who underwent PCNL between January 2009 and September 2013. Of these, 25 patients underwent tubeless PCNL, and 27 patients underwent standard PCNL. The study assessed various factors, including stone burden, analgesic requirement, creatinine levels, renal parenchymal thickness, body mass index (BMI), length of hospital stay, and procedure success rates.The results showed that the tubeless PCNL group had a significantly shorter hospital stay (1.7 days vs. 2.6 days), required fewer narcotic analgesics, and achieved a similar success rate (96% in both groups). No significant differences were observed in other outcomes, such as hemoglobin reduction, creatinine levels, or complication rates. Overall, the study concluded that tubeless PCNL is as safe and effective as standard PCNL for the elderly population, offering advantages such as shorter hospital stays, less pain, and faster recovery (27).

The study by Bilal Habib and colleagues compared the outcomes of using external ureteral catheters (EUC) versus Double-J (DJ) stents in percutaneous nephrolithotomy (PCNL) for patients with renal stones. Their findings revealed that stent-related symptoms were significantly less frequent in patients managed with EUC compared to those with DJ stents (13). This suggests that EUC may be a better option for reducing postoperative discomfort associated with stent-related symptoms. However, no significant differences were observed between the two groups regarding other outcomes, including urinary leak, post-procedure fever, analgesia requirements, and length of hospital stay. These results highlight the potential advantage of EUC in improving patient comfort without compromising other clinical outcomes, offering a viable alternative to DJ stents in the management of renal stones (37).

The findings reported by Adnan Şimşir and colleagues aligned with our review on the comparison of PCNL with Double-J Stent (DJS), nephrostomy, and Kaye nephrostomy balloon catheter, particularly in terms of bleeding and infection rates. Their study demonstrated that percutaneous nephrostomy (PCN) was associated with a lower need for secondary and tertiary interventions compared to DJS, suggesting better long-term efficacy. The significantly earlier and more frequent requirement for re-interventions in the DJS group highlighted potential limitations of this method, including an increased risk of procedural complications such as infection or bleeding due to repeated interventions. Furthermore, the extended time to tertiary intervention in patients treated with PCN suggested a more durable clinical benefit, which was critical in minimizing patient discomfort and reducing healthcare resource utilization (38). These findings reinforced the clinical preference for PCN over DJS in managing symptomatic pregnancy hydronephrosis and underscored the importance of tailoring treatment approaches to optimize patient outcomes

while minimizing adverse events.

The study by Pascal Mouracade and colleagues demonstrated that replacing the Double-J stent with a ureteral catheter in tubeless PCNL was a feasible and safe alternative for patients with moderate stone burden (39). Electrocauterization of bleeding points using a rollerball electrode at the end of the procedure effectively controlled hemorrhage, as evidenced by a minimal mean hemoglobin decrease of 0.8 g/dL and the absence of transfusion requirements. The mean operative time was 71.5 minutes, and the average length of hospitalization was 1.9 days, reflecting a rapid recovery process. Pain intensity was low, with a mean visual analog scale score of 1.87, and 91% of patients had their ureteral catheter removed by the first postoperative day. Complications, including pyelonephritis, urinary extravasation, sustained hematuria, and renal colic, occurred in 15% of cases, with only one patient requiring subsequent Double-J stent placement. These findings highlighted the effectiveness and safety of this technique in reducing complications and optimizing recovery in patients undergoing tubeless PCNL (40).

The study by Siavash Falahatkar and colleagues provided valuable insights into the role of Double-J (DJ) stent insertion in tubeless complete supine PCNL (csPCNL) for patients with staghorn stones. Their findings indicated that DJ stent placement was associated with a higher stone-free rate and a shorter hospital stay compared to the group managed with a ureteral catheter alone (41). However, patients without DJ stents experienced a quicker return to normal life, suggesting potential advantages in postoperative recovery. While no significant differences were observed in major complications, the higher incidence of residual stones in the ureteral catheter group increased the likelihood of renal colic, highlighting the importance of appropriate postoperative management. Although omitting a DJ stent produced acceptable outcomes, the findings suggested that its use might be beneficial in reducing residual stone burden and related complications in cases of staghorn stones.

Emerging technologies, such as biofilm-resistant coatings and antimicrobial agents, hold promise for reducing infection rates associated with all drainage techniques (42). Additionally, advances in minimally invasive PCNL techniques may further minimize bleeding risks, altering the landscape of postoperative management.

Conclusion

The choice of postoperative drainage technique significantly influences the bleeding and infection rates following PCNL. While the Kaye nephrostomy balloon catheter excels in controlling bleeding, Double-J stents offer superior infection control and patient comfort. Nephrostomy tubes, though versatile, carry higher risks of both bleeding and infection. Clinicians must weigh these factors against individual patient profiles to optimize outcomes. By integrating evidence-based practices and embracing technological advancements, healthcare providers can enhance the safety and efficacy of PCNL, ensuring better care for patients with nephrolithiasis.

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