THE JOURNAL of UROLOGY®
www.auajournals.org/journal/juro

## New Technologies and Techniques

## JU Insight

OPEN

# A Randomized, Single-Blind Clinical Trial Comparing Robotic-Assisted Fluoroscopic-Guided with Ultrasound-Guided Renal Access for Percutaneous Nephrolithotomy

Kazumi Taguchi, Shuzo Hamamoto, Atsushi Okada et al.

Correspondence: Shuzo Hamamoto (email: hamamo10@med.nagoya-cu.ac.jp).

*Full-length article available at auajournals.org/10.1097/JU.0000000000002749.*

**Study Need and Importance:** Percutaneous nephrolithotomy (PCNL) is an efficient procedure and thereby is the gold standard for the treatment of large renal stones. However, creating an accurate percutaneous needle puncture into the renal collecting system is challenging and has a steep learning curve that requires rigorous training of surgeons for achieving appropriate skills. To address this unmet need for quick and accurate skill acquisition, we developed an artificial intelligence-empowered robotic interventional device called automated needle target with x-ray for percutaneous renal access.

**What We Found:** In this randomized controlled trial of 71 patients with renal stones, robotic-assisted fluoroscopic (RAF)-guided renal access demonstrated a comparable single puncture success rate (50.0% vs 34.3%), significantly fewer number of needle punctures (1.8 vs 2.5 times) and shorter needle puncture duration (5.5 vs 8.0 minutes) compared to ultrasound (US)-guided access in PCNL when employed by novice surgeons. No differences were seen in stone-free or complication rates between the 2 groups. Interestingly, RAF guidance reduced the required number of needle punctures by 0.73 times (see Figure).

**Limitations:** Since this was a single-center trial, the results need to be validated worldwide through multicenter trials with a larger case volume. Given our hospital's consistency with daily practice, we compared RAF guidance with freehand US guidance. Therefore, the results of this study may be more applicable to institutes employing US-guided PCNL than others; this might benefit from a comparison between RAF guidance and freehand fluoroscopic guidance.

**Interpretation for Patient Care:** RAF-guided PCNL can be performed as safely and effectively as US-guided PCNL, even by novice surgeons. Its benefits for patients with renal stones are more accurate and faster percutaneous access, potentially reducing the perioperative complication rate. Additionally, this technology can potentially reduce the surgeon's training load and allow for PCNL procedures at a wider range of hospitals.

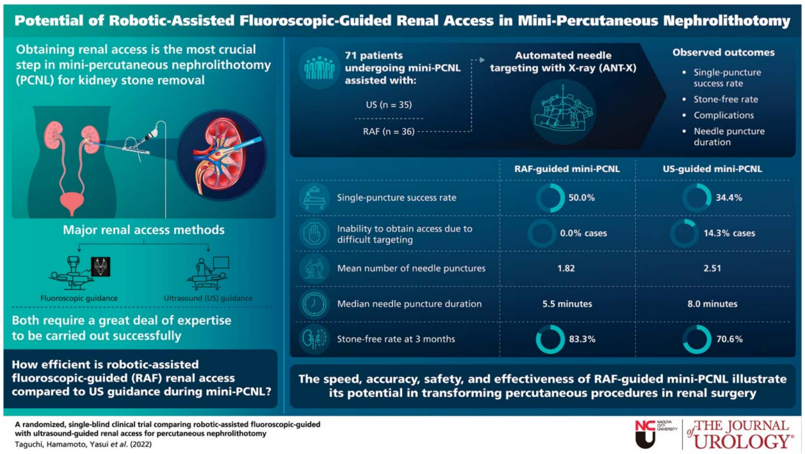


**Figure.** Visual abstract of study.

THE JOURNAL OF UROLOGY®

https://doi.org/10.1097/JU.0000000000002749
Vol. 208, 684-694, September 2022
Printed in U.S.A.

THE JOURNAL of UROLOGY®
www.auajournals.org/journal/juro

OPEN

# A Randomized, Single-Blind Clinical Trial Comparing Robotic-Assisted Fluoroscopic-Guided with Ultrasound-Guided Renal Access for Percutaneous Nephrolithotomy

Kazumi Taguchi,[1] Shuzo Hamamoto,[1]* Atsushi Okada,[1] Teruaki Sugino,[1] Rei Unno,[1,2] Taiki Kato,[1] Hidekatsu Fukuta,[3] Ryosuke Ando,[1] Noriyasu Kawai,[1] Yung Khan Tan[4] and Takahiro Yasui[1]

[1]Department of Nephro-urology, Nagoya City University Graduate School of Medical Sciences, Nagoya, Japan
[2]Department of Urology, University of California, San Francisco, California
[3]Core Laboratory, Nagoya City University Graduate School of Medical Sciences, Nagoya, Japan
[4]Urohealth Medical Clinic, Mt Elizabeth Hospital, Novena, Singapore

**Purpose:** We conducted a randomized, single-blind clinical trial comparing the surgical outcomes of robotic-assisted fluoroscopic-guided (RAF group) and ultrasound-guided (US group) renal access in mini-percutaneous nephrolithotomy (PCNL).

**Materials and Methods:** We recruited patients who underwent mini-PCNL with ureteroscopic assistance for large renal stones between January 2020 and May 2021. Block randomization was performed using online software. Automated needle target with x-ray was used for fluoroscopic-guided renal access in the RAF group. PCNL was performed by residents using a pneumatic lithotripsy system with 16.5Fr/17.5Fr tracts. The primary outcome was single puncture success, and the secondary outcomes were stone-free rate, complication rate, parameters measured during renal access and fluoroscopy time.

**Results:** In total, 71 patients (35 in US group, 36 in RAF group) were enrolled. No difference was seen in the single puncture success rate between the US and RAF groups (34.3% and 50.0%, p=0.2). In 14.3% cases in the US group vs no cases in the RAF group, the resident was unable to obtain access due to difficult targeting (p=0.025). The mean number of needle punctures was significantly fewer, and the median duration of needle puncture was shorter in the RAF group (1.83 vs 2.51 times, p=0.025; 5.5 vs 8.0 minutes, p=0.049, respectively). The stone-free rate at 3 months after surgery was 83.3% and 70.6% in the RAF and US

**ABBREVIATIONS and Acronyms**

AI = artificial intelligence

ANT-X = automated needle targeting with x-ray

CT = computerized tomography

KUB = kidney ureter bladder

PCNL = percutaneous nephrolithotomy

RAF = robotic-assisted fluoroscopic

SFR = stone-free rate

URS = ureteroscopy

US = ultrasound

Submitted January 21, 2022; accepted April 28, 2022; published May 13, 2022.

Support: This work was supported in part by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan (Nos. 19H03791, 20K09544 and 20K21658), and grants from the Hori Science and Arts Foundation, Nitto Foundation and CASIO Science Promotion Foundation.

Conflict of Interest: Kazumi Taguchi and Yung Khan Tan report advisory roles for NDR Medical Technology. The remaining Authors have no conflicts of interest to declare.

Ethics Statement: This study was approved by the Nagoya City University Certified Research Review Board (No. 2019A002) and was conducted in accordance with the Declaration of Helsinki and the Clinical Trials Act. All patients provided written informed consent for participation.

Authors' Contributions: Study concept and design: K. Taguchi, S. Hamamoto, H. Fukuta, Y. K. Tan, T. Yasui. Acquisition of data: K. Taguchi, T. Sugino, R. Unno, T. Kato, N. Kawai. Analysis and interpretation of data: A. Okada, T. Sugino, R. Unno, T. Kato, R. Ando. Drafting of the manuscript: K. Taguchi, S. Hamamoto, T. Sugino, R. Unno. Critical revision of the manuscript for important intellectual content: All authors. Statistical analysis: K. Taguchi, S. Hamamoto, T. Sugino, R. Unno, R. Ando. Obtaining funding: K. Taguchi, S. Hamamoto, T. Yasui. Administrative, technical, or material support: Y. K. Tan, N. Kawai. Supervision: T. Kato, H. Fukuta, Y. K. Tan, A. Okada, N. Kawai, T. Yasui. Other: None.

Japan Registry of Clinical Trials No.: jRCTs042190074.

Data Sharing: Data are available for bona fide researchers who request it from the authors.



* Correspondence: Department of Nephro-urology, Nagoya City University Graduate School of Medical Sciences, Kawasumi 1, Mizuho-cho, Mizuho-ku, Nagoya 4678601, Japan (telephone: +81-52-853-8266; FAX: +81-52-852-3179, email: hamamo10@med.nagoya-cu.ac.jp).

groups, respectively ($p = 0.26$). Multivariate analysis revealed that RAF guidance reduced the mean number of needle punctures by 0.73 times ($p = 0.021$).

**Conclusions:** RAF renal access in mini-PCNL may have further potential applications in this field.

**Key Words:** kidney calculi; nephrolithotomy, percutaneous; ureteroscopy; artificial intelligence; robotic surgical procedures

Percutaneous renal access is the most crucial step during percutaneous nephrolithotomy (PCNL); therefore, most endourologists approach needle puncture and dilation with maximum precaution.[1] The CROES PCNL Study Group reported that PCNL had a 15% overall complication rate, including nearly 5% complications with a Clavien-Dindo grade of III or worse.[2] Clinically significant complications such as massive bleeding requiring blood transfusion and/or embolization, thoracic and bowel injuries, renal pelvis perforation and even sepsis are possible consequences of inadequate renal access during PCNL.[3] Therefore, researchers have been seeking ways to improve techniques and training.

There are 2 major renal access methods: fluoroscopic guidance and ultrasound (US) guidance with or without fluoroscopic image assistance.[4] These 2 techniques are thought to be comparable in terms of postoperative outcomes, including stone-free status and complication rate; however, this finding can only be applied when procedures are performed by experts. A recent systematic review concluded that the learning curve for PCNL was 60 cases for gaining renal access and 105 cases for achieving acceptable stone-free rates (SFRs).[5] While some new modalities such as endoscopic guidance,[6,7] computerized tomography (CT) guidance,[8] real-time virtual sonography assistance[9] and electromagnetic guidance[10] have been introduced in clinical practice, renal access is still challenging for beginners or under specific conditions. Given the complexity of 3D image structure as gauged from intraoperative 2D images provided to surgeons, pre- or intraoperative planning using immersive virtual reality helps us understand the structure and facilitate a safe and effective procedure. However, these techniques still require expertise in targeting the calyx at the time of renal puncture, and subjectivity may cause uncertain or inaccurate access, which results in the development of complications and residual fragments.

In our previous research, we introduced an artificial intelligence (AI) puncture trajectory finder that when integrated with robotic arm movement, can provide robotic-assisted fluoroscopic (RAF)-guided renal puncture in a phantom model, a porcine model and in humans.[11,12] This AI platform, automated needle targeting with x-ray (ANT-X: NDR Medical Technology, Singapore), is thought to be beneficial for residents or novices for achieving acceptable surgical outcomes. To examine the efficacy and safety of RAF-guided renal access during PCNL, we conducted a randomized controlled trial comparing RAF- with US-guided PCNL at an academic center.

## MATERIALS AND METHODS

### Study Design and Participants

This single-center, open-label, randomized clinical trial compared RAF-guided and US-guided mini-PCNL with ureteroscopy (URS) assistance. The study was approved by the Nagoya City University Certified Research Review Board (No. 2019A002) and conducted at Nagoya City University Hospital between October 2019 and September 2021. It was conducted in accordance with the Declaration of Helsinki and the Clinical Trials Act. This study was also registered in the Japan Registry of Clinical Trials (No. jRCTs042190074). All patients provided written informed consent for participation.

The eligibility criteria were as follows: age 16–80 years, and detection of >15 mm renal and/or ureteral stones requiring PCNL. Pregnant or possibly pregnant women, patients with active pyelonephritis or those undergoing antiplatelet/coagulation therapy within 1 week before surgery, those for whom general/lumbar anesthesia was considered difficult by an anesthesiologist and those receiving best supportive care due to terminal carcinoma were excluded.

### Randomization and Outcomes

Patients who visited or were referred to our outpatient clinic were evaluated for study eligibility and recruited by individual physicians. After consent procedures, block randomization was performed using online software stratifying for age (≤30, 31–40, 41–50, 51–60, 61–70, ≥71 years), sex, laterality, total stone burden (≤20, 21–30, 31–40, 41–50, ≥50), hydronephrosis grade (none, mild, moderate, severe, atrophic) and presence of staghorn stones. Each participant was assigned to the US-guided or RAF-guided group by an independent investigator. The surgical team was informed of the allocation a few weeks before the surgery; however, the patients were blinded.

The primary outcome was single puncture success, and the secondary outcomes were SFR, overall complication rate, complication (Clavien-Dindo classification) rates, parameters during renal access and fluoroscopy duration. The successful renal access was defined as the renal access in which a guidewire was placed into the renal collecting system with urine backflow. Stone-free status was defined as follows: no residual fragments larger than 4 mm detected in kidney ureter bladder (KUB) radiography at 1 month after surgery, and no residual

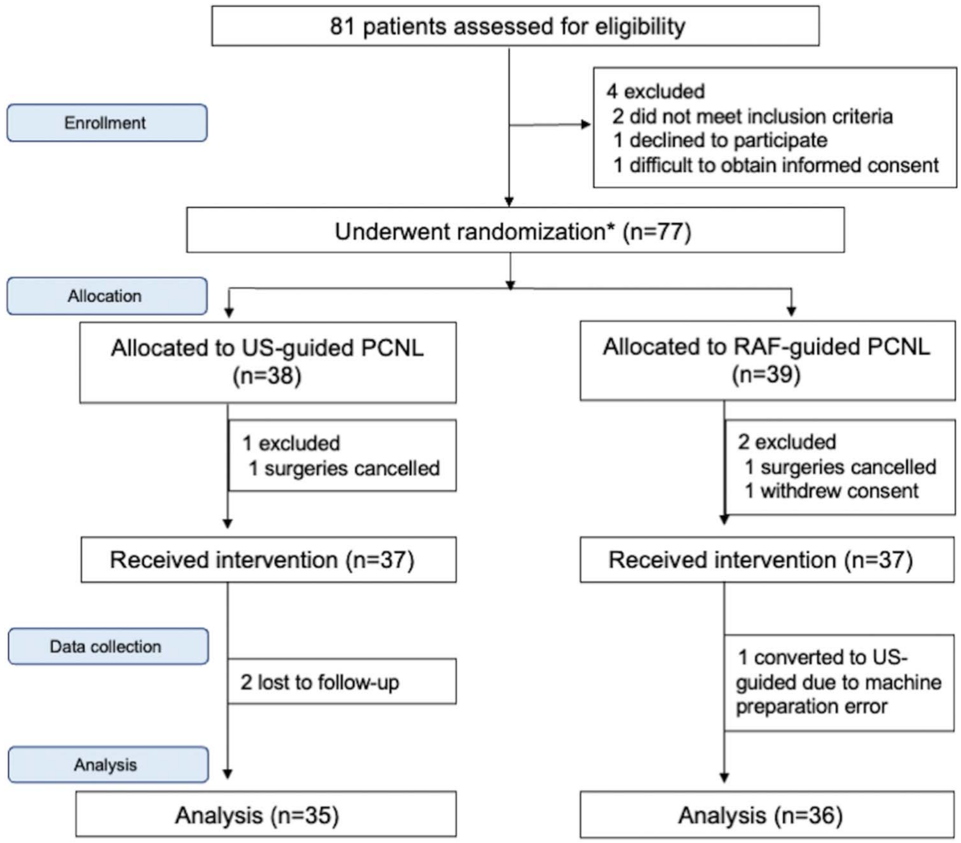


Figure 1. Study flowchart. Asterisk indicates block randomization, which was performed with adjustment for age, sex, laterality, total stone burden, hydronephrosis grade and presence of staghorn stones.

fragments larger than 2 mm detected by CT 3 months after surgery.

The study flowchart is summarized in Figure 1.

## Intervention and Surgical Technique

All PCNLs were performed with URS assistance with or without laser lithotripsy under general anesthesia. We utilized a pneumatic lithotripsy system (Swiss LithoClast® Master J, Electro Medical Systems, Nyon, Switzerland) through a mini-percutaneous nephrolithotomy (MIP, Karl Storz, Tuttlingen, Germany) with a 16.5Fr/17.5Fr, 21Fr/22Fr or 24Fr operating sheath depending on stone volume and complexity. For percutaneous renal puncture, a 24-gauge trocar needle (Hanaco Medical Co., Ltd., Saitama, Japan) was used; thereafter, the percutaneous tract into the renal collecting system was made by a 1-step dilation tool.

For RAF-guidance, ANT-X (see supplementary Figure, https://www.jurology.com) was utilized to gain renal access. The procedure was performed with the patient in the prone position. After fluoroscopic visualization of the renal collecting system using contrast medium, the robot arm was mounted on the patient's back, and the needle tip was marked on the skin above the desired calyx. The puncture trajectory alignment was implemented by applying the bull's-eye technique by AI calculation based on the location between markers and a needle tip point. The surgeon inserted a needle into the target calyx by confirming the depth through a tilted fluoroscopic view (Fig. 2). In all cases, the procedure from the ANT-X setup through the needle insertion was performed by a single surgeon, who was a novice in fluoroscopic-guided percutaneous access. The remaining procedures, including tract creation and fragmentation, were performed by a main PCNL surgeon in each case.

For US guidance, ARIETTA 65® (Hitachi, Tokyo, Japan) with 6-1 or 5-1 MHz biopsy transducers (FUJIFILM Healthcare Co., Tokyo, Japan) was used for renal access. The procedure was performed with the patient in either the prone or Galdakao modified supine Valdivia position, based on surgeon's decision considering stone and anatomical features. After needle insertion into the renal collecting system, the percutaneous tract was created mainly by fluoroscopic guidance with or without URS assistance. The primary surgeon who performed the first attempt at renal puncture in each case was a resident.

We fragmented the stones using a pneumatic lithotripsy probe (power 100%, frequency 12 Hz), and fragments were removed from the percutaneous tract by continuous backflow of percutaneous and ureteroscopic irrigation. We placed a 4.8Fr ureteral stent in all cases and 12Fr nephrostomy tubes in case of residual fragments or risk of postoperative bleeding/infection.

## Statistical Analysis

The null hypothesis was that the RAF group had a superior single needle puncture over the US group. This was based on the results of the prior phantom study, showing

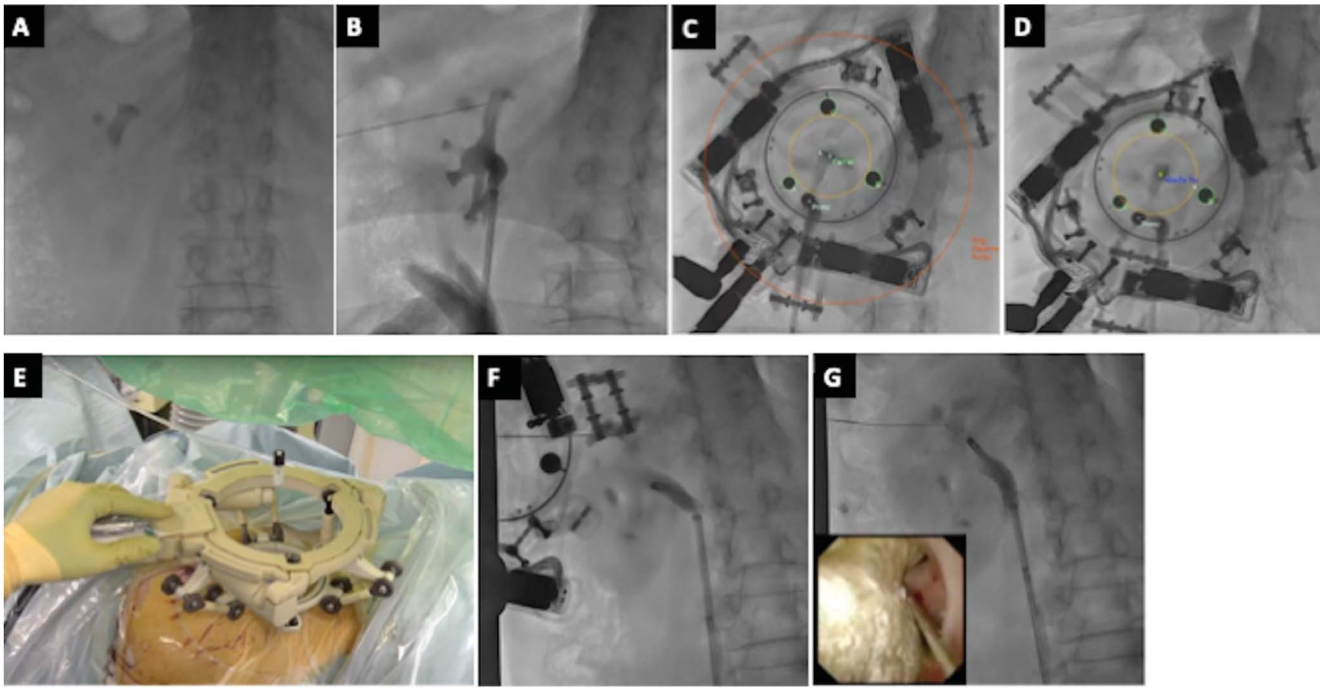


Figure 2. RAF percutaneous renal access. *A*, fluoroscopic image of an upper calyceal stone. *B*, a needle insertion point on the patient's skin is marked under the fluoroscopic confirmation of renal collecting system. *C* and *D*, the software monitor view connected to the device and C-arm. The robotic arm is mounted on the patient's back and keeps the target calyx in the inner yellow circle. Three marker balls are detected for calibration, then a needle is set in the holder before alignment (*C*). After the alignment, the needle trajectory is determined as a bull's-eye position and automatically positioned by the robotic arm (*D*). *E*, the external view of the device with needle after the alignment. *F*, the needle is inserted from the targeted upper calyx. The C-arm is tilted to visualize the depth. *G*, the wire placement into the collecting system is confirmed by both fluoroscopy and the ureteroscopic view (inset).

95% and 70% single needle puncture rate in the RAF and US groups, respectively.[13] The sample size was calculated with a 0.05 type 1 error, 0.8 power, and a 10% superior margin considering differences between the phantom study and the real clinical setting. Therefore, a minimum sample size was set for 35 per group.

All statistical analyses were performed using EZR software (R Foundation for Statistical Computing, Vienna, Austria),[14] and significance was set at $p < 0.05$. Categorical variables, such as single puncture success as a primary outcome, and SFR, complications and other perioperative parameters as secondary outcomes, were compared using chi-square and Fisher's exact tests. Continuous variables, such as duration of each surgical step, including fluoroscopy and laboratory data changes, were compared using 2-sample t-tests and the Mann-Whitney U test, depending on the distribution pattern for secondary and other outcome evaluation. Since the sample size of this randomized controlled trial was small, there were potential confounding variables unequally distributed between the 2 arms. Therefore, as the subgroup analyses, logistic and linear regression was performed to mitigate potential inequality of covariates between the groups. In particular, the SFR and overall complication were assessed with adjusting covariates assumed to impact these outcomes during the surgical planning, using a logistic regression model at the study beginning. The needle puncture and percutaneous access duration, as well as the number of punctures, were assessed with covariates that estimated potential unequal distribution, using a linear regression model.

## RESULTS

In total, 71 patients (35 in US group, 36 in RAF group) were enrolled. The mean age at surgery was 59.7 and 55.9 years in the US and RAF groups, respectively. Approximately 40% patients were female, and approximately one-third of stones were located in the ureteropelvic junction. Twenty-six percent and 36% of patients had staghorn stones in the US and RAF groups, respectively. Other preoperative factors in the 2 groups were comparable (Table 1).

### Primary Outcome and Puncture Details

The single puncture success rate was 34.3% and 50.0% in the US and RAF groups, respectively ($p=0.2$). However, the mean number of needle punctures was significantly smaller in the RAF group (1.82 times vs 2.51 times, $p=0.025$). In the US group, the resident was unable to obtain access for 14.3% cases; this was not seen in the RAF group ($p=0.025$, Table 2).

### Secondary Outcomes

The median needle puncture duration was also significantly shorter in the RAF group (5.5 minutes vs 8.0 minutes, $p=0.049$), whereas no differences were seen in percutaneous access and fluoroscopic

**Table 1.** *Preoperative characteristics of study participants*

| | US-Guided | | RAF-Guided | |
|---|---|---|---|---|
| No. pts | 35 | | 36 | |
| Mean yrs age (SD) | 59.7 | (11.5) | 55.9 | (13.9) |
| No. female sex (%) | 14 | (40.0) | 14 | (38.9) |
| No. lt side (%) | 17 | (48.6) | 17 | (47.2) |
| Mean kg/m$^2$ BMI (SD) | 24.12 | (4.39) | 25.02 | (4.93) |
| No. main stone location (%): | | | | |
| Upper calyx | 8 | (22.9) | 2 | (5.6) |
| Middle calyx | 7 | (20.0) | 12 | (33.3) |
| Lower calyx | 6 | (17.1) | 10 | (27.8) |
| UPJ | 12 | (34.3) | 12 | (33.3) |
| Proximal | 1 | (2.9) | 0 | (0.0) |
| Distal | 1 | (2.9) | 0 | (0.0) |
| No. staghorn (%): | | | | |
| Partial | 6 | (17.1) | 11 | (30.6) |
| Complete | 3 | (8.6) | 2 | (5.6) |
| No. bacteriuria (%) | 14 | (40.0) | 12 | (33.3) |
| Median cm$^3$ stone vol (IQR) | 6.58 (3.47, 14.48) | | 6.58 (4.01, 15.67) | |
| Median HU stone density (IQR) | 1,283 | (1,081, 1,481) | 1,367 | (1,181, 1,500) |
| No. hydronephrosis (%): | 11 | (31.4) | 11 | (30.5) |
| Mild | 1 | (2.9) | 2 | (5.6) |
| Moderate | | | | |
| Severe | 3 | (8.6) | 1 | (2.8) |
| No. pre-stenting (%) | 6 | (17.1) | 4 | (11.1) |

duration between the 2 groups. SFR, confirmed by KUB radiographs, was 88.6% and 97.1% at 1 month after surgery, and 70.6% and 83.3% at 3 months after surgery in the US and RAF groups, respectively (p=0.356 and p=0.26, respectively). No between-group differences were observed in the overall complication rate, complications within 1 month after surgery, or complications between 1 and 3 months after surgery (Table 2).

**Table 2.** *Primary and secondary outcomes*

| | US-Guided | | RAF-Guided | | p Value |
|---|---|---|---|---|---|
| No. pts | 35 | | 36 | | |
| No. single puncture success (%) | 12 | (34.3) | 18 | (50.0) | 0.2 |
| No. needle punctures (%) | 2.51 | (1.50) | 1.83 | (0.94) | 0.025 |
| No. cases resident was unable to obtain access (%) | 5 | (14.3) | 0 | (0.0) | 0.025 |
| Median mins needle puncture duration (IQR)* | 8.00 (4.50, 14.50) | | 5.50 (3.00, 10.00) | | 0.049 |
| Median mins percutaneous access duration (IQR)† | 17.0 | (12.0, 26.5) | 14.0 | (8.8, 19.0) | 0.11 |
| Median seconds fluoroscopic duration (IQR) | 594 | (447, 778) | 660 | (534, 924) | 0.18 |
| No. stone-free status 1 mo after surgery (%)‡ | 31 | (88.6) | 34 | (97.1) | 0.4 |
| No. stone-free status 3 mos after surgery (%)§ | 24 | (70.6) | 30 | (83.3) | 0.3 |
| No. overall complications (%) | 6 | (17.1) | 10 | (27.8) | 0.4 |
| No. complication within 1 mo after surgery (%):ǁ | | | | | 0.9 |
| I | 2 | (5.7) | 2 | (5.6) | |
| II | 3 | (8.6) | 5 | (13.9) | |
| III | 1 | (2.9) | 2 | (5.6) | |
| No. complication between 1 and 3 mos after surgery (%):ǁ | | | | | 0.17 |
| I | 3 | (8.8) | 0 | (0.0) | |
| II | 1 | (2.9) | 1 | (2.8) | |

* Duration between the start of imaging to visualize the target calyx and the placement of a guidewire inside the renal collecting system.
† Duration between the start of imaging to visualize the target calyx and the percutaneous tract placement into the renal collecting system.
‡ Residual fragments were defined as less than 4 mm in size by KUB images.
§ Residual fragments were defined as less than 2 mm in size by CT images.
ǁ Complications were shown as Clavien-Dindo classification.

Table 3 summarizes the intra- and postoperative parameters. PCNL was performed predominantly by residents in both groups (74.3% and 55.6% in the US and RAF groups, respectively; p=0.3). The median number of prior PCNL cases that lead surgeons had experienced was 14 and 12 cases in the US and RAF groups, respectively (p=0.2). The groups showed similar trends in the selection of renal calyces for percutaneous access. Patients' positioning was different between the US and RAF groups (prone in 60.0% and 94.4%, respectively; p=0.001). There were no significant differences in other intraoperative parameters. There were no significant differences in specific complications, including serum leukocyte increase, decrease in hemoglobin, and estimated glomerular filtration rate at 1 day and at 3 months after surgery.

Further causal evaluation with logistic regression analysis demonstrated that larger percutaneous tract size, defined as either 22Fr or 24Fr, which was larger than the size used in the majority of cases (17.5Fr), was associated with an increased odds ratio for a higher overall complication rate (OR=13.7, p=0.032). No association was found between SFR 3 months after surgery and factors including RAF-guided renal access (Table 4). Linear regression analysis revealed that only RAF-guided renal access was associated with a decreased number of renal punctures (estimate −0.73, p=0.021). Preoperative and intraoperative factors, including RAF-guided renal access, were not associated with needle puncture and percutaneous access duration (Table 5).

## DISCUSSION

In this study, the RAF group demonstrated a smaller number of needle punctures and a shorter needle puncture duration, which can positively impact the patient's outcome. In fact, renal access during PCNL is directly related to surgical outcomes, including complications.[15] While no differences were found in postoperative complications between the US and RAF groups in our trial, Gorbachinsky et al reported that multiple renal accesses were associated with postoperative decrease in renal function in PCNL.[16] Therefore, fewer needle punctures might be beneficial for postoperative renal function preservation. In addition, consistent with other large volume evidence,[17] the current study revealed that cases with larger percutaneous tract size (22Fr and 24Fr sheaths) were associated with a higher complication risk. This finding indicated that RAF-guided percutaneous access did not

**Table 3.** *Intra- and postoperative parameters comparison between US-guided and RAF-guided renal access*

| | US-Guided | | RAF-Guided | | p Value |
|---|---|---|---|---|---|
| No. pts | 35 | | 36 | | |
| No. main PCNL surgeon (%): | | | | | 0.3 |
| Resident | 26 | (74.3) | 20 | (55.6) | |
| Fellow | 4 | (11.4) | 7 | (19.4) | |
| Attending | 5 | (14.3) | 9 | (25.0) | |
| Median prior PCNL cases lead surgeons had experienced (IQR) | 14 | (10, 58) | 12 | (10, 18) | 0.2 |
| No. puncture calyx (%): | | | | | 0.8 |
| Upper | 14 | (40.0) | 11 | (30.6) | |
| Middle | 10 | (28.6) | 13 | (36.1) | |
| Lower | 11 | (31.4) | 12 | (33.3) | |
| No. Fr tract size (%): | | | | | 0.4 |
| 17.5 | 32 | (91.4) | 31 | (88.7) | |
| 22 | 1 | (2.9) | 5 | (11.2) | |
| 24 | 2 | (5.7) | 0 | (0.0) | |
| No. positioning (%): | | | | | 0.001 |
| Prone | 21 | (60.0) | 34 | (94.4) | |
| Supine | 14 | (40.0) | 2 | (5.6) | |
| No. tubeless (%) | 29 | (82.9) | 29 | (80.6) | >0.9 |
| Median mins device setup duration (IQR) | 4.00 | (2.00, 5.00) | 4.50 | (3.00, 7.00) | 0.5 |
| Median mins fragmentation duration (IQR) | 52.0 | (33.0, 84.0) | 61.0 | (35.8, 94.0) | 0.8 |
| Median mins surgical duration (IQR) | 103 | (75, 141) | 112 | (82, 149) | 0.5 |
| No. fever (%)* | 3 | (8.6) | 4 | (11.1) | >0.9 |
| No. fragment obstruction (%) | 3 | (8.6) | 0 | (0.0) | 0.12 |
| No. renal hemorrhage (%) | 0 | (0.0) | 3 | (8.3) | 0.2 |
| No. urinary damage (%) | 7 | (20.0) | 4 | (11.1) | 0.3 |
| No. organ injury (%) | 1 | (2.9) | 1 | (2.8) | >0.9 |
| No. sepsis (%) | 1 | (2.9) | 1 | (2.8) | >0.9 |
| Median serum WBC$\times 10^3/\mu l$ increase 1 day after surgery (IQR) | 3.30 | (1.90, 5.50) | 3.30 | (1.27, 4.72) | 0.4 |
| Median gm/l serum Hb decrease 1 day after surgery (IQR) | 0.60 | (0.25, 1.50) | 0.90 | (0.28, 1.60) | 0.6 |
| Median ml/min/1.73 $m^2$ serum eGFR decrease 1 day after surgery (IQR) | −0.60 | (−3.70, 4.85) | 2.15 | (−3.73, 8.23) | 0.4 |
| Median serum WBC$\times 10^3/\mu l$ increase 3 mos after surgery (IQR) | −0.40 | (−1.00, 0.40) | −0.40 | (−0.95, 0.55) | 0.8 |
| Median gm/l serum Hb decrease 3 mos after surgery (IQR) | 0.00 | (−0.50, 0.60) | −0.05 | (−0.70, 0.30) | 0.5 |
| Median ml/min/1.73 $m^2$ serum eGFR decrease 3 mos after surgery (IQR) | 1.30 | (−3.20, 7.10) | 1.15 | (−0.77, 3.85) | >0.9 |

*eGFR*, estimated glomerular filtration rate. *Hb*, hemoglobin. *WBC*, white blood cell count.
* Defined as greater than 38.5C.

independently influence the occurrence of complications; however, tract size did. Moreover, in 14.3% of US-guided punctures, a change of surgeon was needed owing to the difficulties associated with gaining access, whereas no surgeon change was required during RAF-guided renal access. Percutaneous access was used by most residents in this study, indicating that US-guided access was challenging for them. RAF-guided access was achievable by a novice surgeon. This may fill the gap between experts and trainees in the real-world trend of teaching facilities—wherein not all procedures are performed by experts, and similar outcomes between US- and fluoroscopy-guided procedures are expected.[4]

**Table 4.** *Logistic regression analysis of factors associated with surgical outcomes*

| | Stone-Free Status 3 Mos after Surgery | | Overall Complications | |
|---|---|---|---|---|
| | OR (95% CI) | p Value | OR (95% CI) | p Value |
| Intercept | 0.57 (0.02—17.2) | 0.8 | 0.93 (0.02—34.8) | >0.9 |
| RAF guidance | 2.06 (0.59—7.14) | 0.3 | 1.62 (0.45—5.76) | 0.5 |
| Attending surgeon performing PCNL | 0.77 (0.20—2.92) | 0.7 | 1.59 (0.43—5.90) | 0.5 |
| Larger percutaneous tract size* | 1.51 (0.16—14.8) | 0.7 | 13.7 (1.3—151) | 0.032 |
| BMI | 1.08 (0.94—1.24) | 0.3 | 0.94 (0.81—1.08) | 0.4 |
| Stone vol | 0.98 (0.95—1.01) | 0.3 | 0.98 (0.94—1.02) | 0.3 |

*BMI*, body mass index.
* Either 22Fr or 24Fr sheath compared with 17.5Fr sheath.

Robotic-assisted surgeries have been widely used by urologists and have become the standard approach for several subspecialties, with a surge of research interest.[18] As in other fields, kidney stone surgeons may have a greater appreciation of robotic technologies, such as the Avicenna Roboflex (ELMED Medical Systems, Ankara, Turkey) for URS, which controls scope maneuver and supports lithotripsy from a distant console.[19] Robotic percutaneous access to the kidney, introduced by John Hopkins University, enables the control of percutaneous needle insertion with a robot arm while surgeons monitor live fluoroscopic images.[20] There are alternative image navigation tools that use fluoroscopic guidance, such as StealthStation™ (Medtronic, Minneapolis, Minnesota), Micromate™ (iSYS, Kitzbühel, Austria) and AcuBot (Georgetown Medical Center, Washington, D.C.).[21] These devices provide more precise percutaneous access by holding needles and fine-tuning needle movement; however, needle trajectory toward the

**Table 5.** *Linear regression analysis of factors associated with renal access*

| | Needle Puncture Duration | | Percutaneous Access Duration | | No. Punctures | |
|---|---|---|---|---|---|---|
| | Estimate (95% CI) | p Value | Estimate (95% CI) | p Value | Estimate (95% CI) | p Value |
| Intercept | 1.27 (−9.07—11.6) | 0.8 | 13.2 (−0.58—26.9) | 0.06 | 1.51 (−0.17—3.19) | 0.078 |
| RAF guidance | −3.76 (−7.59—0.07) | 0.054 | −3.70 (−8.78—1.39) | 0.15 | −0.73 (−1.36—−0.11) | 0.021 |
| Attending surgeon performing PCNL | 2.75 (−1.45—6.95) | 0.2 | 1.59 (−3.99—7.17) | 0.6 | 0.07 (−0.61—0.75) | 0.8 |
| BMI | 0.32 (−0.09—0.72) | 0.12 | 0.07 (−0.47—0.6) | 0.8 | 0.03 (−0.04—0.09) | 0.4 |
| Stone vol | −0.03 (−0.12—0.06) | 0.5 | 0.11 (0—0.23) | 0.059 | 0.01 (−0.01—0.02) | 0.5 |
| Neg preop hydronephrosis | 2.89 (−0.86—6.64) | 0.13 | 4.93 (−0.06—9.91) | 0.053 | 0.39 (−0.22—1) | 0.2 |

*BMI*, body mass index.

target has to be navigated by the surgeons themselves. In contrast, the current robotic technique, ANT-X, used in this study has a unique feature: automation of the needle puncture trajectory provided by the AI platform. Our study showed that this technique allows the novice surgeon to perform renal access safely and effectively with less needle puncture frequency and duration compared with a conventional US-guided procedure. Certainly, these robotic-assisted surgeries have the risk of device malfunction; therefore, backups and training for alternative methods should always be performed as a precaution. Indeed, in our study, 1 case was converted to US-guided PCNL due to a machine preparation error. In addition to this safety evaluation, the cost-effectiveness of robotic-assisted surgeries also needs to be evaluated.

Several other modalities support renal access during PCNL. Under US guidance, real-time virtual sonography provides the fusion of real-time US images and preoperative CT images that are input into the US machine software beforehand.[9] The individual anatomical analysis is also achieved with 3D printing, which is mainly utilized for simulation. Ghazi et al reported the usefulness of patient-specific simulation using a 3D-printed hydrogel model for PCNL training.[22] Moreover, technological innovation with 3D models has provided us with a cross-reality tool for the simulation and navigation of renal access during PCNL.[23] Virtual reality,[24] augmented reality using an iPad® (Apple Inc., Cupertino, California)[25] and mixed-reality hologram,[26] can reduce radiation exposure as well as renal puncture time or number of attempts. Electromagnetic-guided percutaneous access has promising features with direct navigation from the ureteroscope tip, which provides semiautomatic targeting with minimal radiation and a short learning curve.[10,27] These modalities are examples that improve anatomical understanding and thus aid in quicker preoperative planning and navigation of the surgeon's self-maneuver of the needle puncture. However, the technique for adjusting the angle toward the target calyx with 2D intraoperative images is still challenging for young or inexperienced urologists, and the image navigation tool requires extra time to prepare. Although our previous benchtop study showed that the device setup time was longer in RAF-guided puncture than that in US-guided puncture, the current clinical trial demonstrated no between-group difference in device setup time. We assumed that this comparable result was due to the support of our medical engineering staff, who prepared the device simultaneously.

One could overcome this technical difficulty in percutaneous needle targeting by the application of AI. Checcucci et al updated promising research utilizing AI for percutaneous needle puncture.[23] Needle tracking with precise segmentation of US images could be achieved by deep learning architecture. It could also provide needle trajectory prediction during percutaneous puncture. Moreover, the robotic system to support US-guided percutaneous punctures by fine-tuning the needle position is available in proof of concept status.[28] Combining these needle detection and trajectory calculations may be an ideal technology integration to achieve precise percutaneous access. RAF-guided renal access consists of real-time image and trajectory navigation. Since no cases lost the needle targeting into the targeted calyx by a single surgeon, this platform may be the most promising solution for future automatic percutaneous puncture.

This study had several limitations. Although we calculated the sample size based on the results of a previous phantom study, a multicenter study with a larger volume may be statistically more effective to obtain more sophisticated evidence. The comparison between US- and fluoroscopic-guided robotic techniques might reflect more than just the difference between freehand and RAF-guided percutaneous access. In addition, the cost estimation should be provided for comparing these 2 methods in order for RAF to be applied to our daily practice. Finally, the heterogeneity of surgical methods, such as percutaneous tract size, types of lead surgeon at the PCNL side and patients' positioning, were potential confounding factors that masked the influence of robotic assistance on the percutaneous access outcome. However, we believe that these results reflect real-world practice in terms of the recent global trend whereby the PCNL technique has been shifting to US guidance or utilizing new navigation systems.

## CONCLUSIONS

RAF-guided PCNL can be performed as safely and effectively as US-guided PCNL, even by novice surgeons, using fluoroscopic guidance. It may provide more accurate and faster percutaneous access, which could potentially reduce the perioperative complication rate. With their promising features, robotic-assisted platforms will be a beneficial innovation in percutaneous procedures.

## ACKNOWLEDGMENTS

We thank the operating room, radiology and medical engineering staff at Nagoya City University Hospital who supported the installation of the RAF-guided system as well as NDR Medical Technology for their help in ANT-X preparation. We would also like to thank Editage for English proofreading.

## REFERENCES

1. Rassweiler J, Rassweiler M-C and Klein J: New technology in ureteroscopy and percutaneous nephrolithotomy. Curr Opin Urol 2016; **26:** 95.
2. De La Rosette J, Assimos D, Desai M et al: The clinical research office of the Endourological Society Percutaneous Nephrolithotomy Global Study: indications, complications, and outcomes in 5803 patients on behalf of the CROES PCNL study group. J Endourol 2011; **25:** 11.
3. Seitz C, Desai M, Häcker A et al: Incidence, prevention, and management of complications following percutaneous nephrolitholapaxy. Eur Urol 2012; **61:** 146.
4. Corrales M, Doizi S, Barghouthy Y et al: Ultrasound or fluoroscopy for percutaneous nephrolithotomy access, is there really a difference? A review of literature. J Endourol 2021; **35:** 241.
5. Quirke K, Aydin A, Brunckhorst O et al: Learning curves in urolithiasis surgery: a systematic review. J Endourol 2018; **32:** 1008.
6. Khan F, Borin JF, Pearle MS et al: Endoscopically guided percutaneous renal access: "seeing is believing." J Endourol 2006; **20:** 451.
7. Patel MB, Mason BM and Hoenig DM: Retrograde endoscopic-assisted percutaneous renal access: a novel "lasso" technique to achieve rapid secure access to the collecting system. J Endourol 2008; **22:** 591.
8. Ghani KR, Patel U and Anson K: Computed tomography for percutaneous renal access. J Endourol 2009; **23:** 1633.
9. Hamamoto S, Unno R, Taguchi K et al: A new navigation system of renal puncture for endoscopic combined intrarenal surgery: real-time virtual sonography-guided renal access. Urology 2017; **109:** 44.
10. Lima E, Rodrigues PL, Mota P et al: Ureteroscopy-assisted percutaneous kidney access made easy: first clinical experience with a novel navigation system using electromagnetic guidance (IDEAL stage 1). Eur Urol 2017; **72:** 610.
11. Taguchi K, Hamamoto S, Kato T et al: Robot-assisted fluoroscopy-guided renal puncture for endoscopic combined intrarenal surgery: a pilot single-centre clinical trial. BJU Int 2021; **127:** 307.
12. Oo MM, Gandhi HR, Chong K-T et al: Automated needle targeting with x-ray (ANT-X)—robot-assisted device for percutaneous nephrolithotomy (PCNL) with its first successful use in human. J Endourol 2021; **35:** e919.
13. Taguchi K, Hamamoto S, Okada A et al: Robot-assisted fluoroscopy versus ultrasound-guided renal access for nephrolithotomy: a phantom model benchtop study. J Endourol 2019; **33:** 987.
14. Kanda Y: Investigation of the freely available easy-to-use software EZR' for medical statistics. Bone Marrow Transpl 2013; **48:** 452.
15. Knoll T, Daels F, Desai J et al: Percutaneous nephrolithotomy: technique. World J Urol 2017; **35:** 1361.
16. Gorbachinsky I, Wood K, Colaco M et al: Evaluation of renal function after percutaneous nephrolithotomy—does the number of percutaneous access tracts matter? J Urol 2016; **196:** 131.
17. Zeng G, Cai C, Duan X et al: Mini percutaneous nephrolithotomy is a noninferior modality to standard percutaneous nephrolithotomy for the management of 20—40 mm renal calculi: a multicenter randomized controlled trial. Eur Urol 2021; **79:** 114.
18. Jackson SR and Patel MI: Robotic surgery research in urology: a bibliometric analysis of field and top 100 articles. J Endourol 2019; **33:** 389.
19. Saglam R, Muslumanoglu AY, Tokatlı Z et al: A new robot for flexible ureteroscopy: development and early clinical results (IDEAL stage 1—2b). Eur Urol 2014; **66:** 1092.
20. Su LM, Stoianovici D, Jarrett TW et al: Robotic percutaneous access to the kidney: comparison with standard manual access. J Endourol 2002; **16:** 471.
21. Stoianovici D, Cleary K, Patriciu A et al: AcuBot: a robot for radiological interventions. IEEE Trans Robot Autom 2003; **19:** 927.
22. Ghazi A, Melnyk R, Farooq S et al: Validity of a patient-specific percutaneous nephrolithotomy (PCNL) simulated surgical rehearsal platform: impact on patient and surgical outcomes. World J Urol 2022; **40:** 627.
23. Checcucci E, Amparore D, Volpi G et al: Percutaneous puncture during PCNL: new perspective for the future with virtual imaging guidance. World J Urol 2022; **40:** 639.
24. Parkhomenko E, O'Leary M, Safiullah S et al: Pilot assessment of immersive virtual reality renal models as an educational and preoperative planning tool for percutaneous nephrolithotomy. J Endourol 2019; **33:** 283.
25. Rassweiler-Seyfried M-C, Rassweiler JJ, Weiss C et al: iPad-assisted percutaneous nephrolithotomy (PCNL): a matched pair analysis compared to standard PCNL. World J Urol 2020; **38:** 447.
26. Porpiglia F, Checcucci E, Amparore D et al: Percutaneous kidney puncture with three-dimensional mixed-reality hologram guidance: from preoperative planning to intraoperative navigation. Eur Urol 2022; **81:** 588.
27. Borofsky MS, Rivera ME, Dauw CA et al: Electromagnetic guided percutaneous renal access outcomes among surgeons and trainees of different experience levels: a pilot study. Urology 2020; **136:** 266.
28. Chen S, Wang F, Lin Y et al: Ultrasound-guided needle insertion robotic system for percutaneous puncture. Int J Comput Assist Radiol Surg 2021; **16:** 475.

## EDITORIAL COMMENTS

Renal access is the single most important step to completing a successful percutaneous nephrolithotomy (PCNL). Renal access obtained by a urologist is associated with increased stone-free rates, decreased complications, decreased length of stay and decreased hospital costs when compared to renal access obtained by a radiologist.[1–3] Data from U.S. insurance claims databases indicate that urologist-obtained access is on the rise, increasing from 13% in 2007 to 32% in 2017.[3] If urologist-obtained access results in positive patient outcomes, why do the majority of urologists still rely on radiologists to obtain access for PCNL? A major barrier continues to be the learning curve. As the authors point out, techniques such as ultrasound guidance for access have decreased the learning curve compared to traditional fluoroscopy guidance, but even at less than 20 cases to learn ultrasound access, urologists experience variable training in obtaining access during residency/fellowship and thus do not uniformly finish their training feeling comfortable with obtaining their own access. Clearly there remains a clinical need to get us closer to 100% urologist-obtained access for PCNL.

Robotic assistance may represent a solution for this clinical need. In this randomized, single-blind trial, the authors found a decreased number of needle punctures, decreased access time and increased success of trainees with robotic-assisted fluoroscopic-guided vs ultrasound-guided renal access, with no difference in stone-free rates or complications between the groups. Pairing an artificial intelligence puncture trajectory finder with robotic-assisted needle access represents a novel advancement of technology. We often see new technologies with no clinical applicability. These results may represent an encouraging new potential avenue to increase urologist-obtained renal access with new technology matched to a clinical need.

**Gregory W. Hosier[1] and Thomas Chi[1]**
[1]*Department of Urology*
*University of California*
*San Francisco, California*

## REFERENCES

1. Tomaszewski JJ, Ortiz TD, Gayed BA et al: Renal access by urologist or radiologist during percutaneous nephrolithotomy. J Endourol 2010; **24:** 1733.
2. Speed JM, Wang Y, Leow JJ et al: The effect of physician specialty obtaining access for percutaneous nephrolithotomy on perioperative costs and outcomes. J Endourol 2017; **31:** 1152.
3. Metzler IS, Holt S and Harper JD: Surgical trends in nephrolithiasis: increasing de novo renal access by urologists for percutaneous nephrolithotomy. J Endourol 2021; **35:** 769.

This study compares 2 techniques for gaining percutaneous access for mini-percutaneous nephrolithotomy (PCNL). One is the traditional ultrasound (US)-guided method. The novel method involves an artificial intelligence (AI)-guided robotic arm using fluoroscopic (RAF) guidance to make the puncture into the selected calyx for percutaneous stone removal. The study compares the 2 techniques with respect to time for puncture, number of punctures, complication rate, stone-free rate and other data points of interest.

The patient population was approximately equal (35 in US group vs 36 in RAF group), and all other parameters were comparable between groups. Urology residents performed the initial puncture in each group, but in 14% of the US patients, puncture failed initially and it was necessary to switch surgeons to complete the puncture, suggesting US guidance has a more difficult learning curve compared to the RAF technique.[1] This is not surprising since the AI and robotic arm do the work once the instrument is set up.

Although not yet readily available in the United States, automated needle targeting with x-ray with programmed AI seems to be a new way to automate and simplify percutaneous puncture for PCNL. It was quicker and more accurate, stone-free rates were better in the RAF group, needle puncture required fewer attempts, complications were fewer, and based on this initial study it would seem the RAF method is superior to the traditional US-guided method. The only advantages I can see for US guidance are less fluoroscopy time[2] and the (US) equipment is less costly.

One should consider the circumstance where a robot fails. With the da Vinci® system, one must revert to pure laparoscopy or convert to an open surgical procedure to complete the operation.[3] Since robots are complex and can fail intraoperatively, urology trainees should still learn other techniques for PCNL puncture, including US and fluoroscopic guidance. The authors point this out in the Discussion.

In summary, this is a well-done, novel study showing the feasibility and the advantages of automating renal puncture, one of the most critical parts of achieving successful stone removal with the PCNL procedure.

**Mark J. Noble[1]**
[1]*Department of Urology*
*Cleveland Clinic Lerner College of Medicine*
*Cleveland, Ohio*

## REFERENCES

1. Usawachintachit M, Masic S, Allen IE et al: Adopting ultrasound guidance for prone percutaneous nephrolithotomy: evaluating the learning curve for the experienced surgeon. J Endourol 2016; **30:** 856.
2. Bayram Ilikan G, Karabulut B and Tiryaki HT: Can ultrasound guidance reduce radiation exposure significantly in percutaneous nephrolithotomy in pediatric patients? Urolithiasis 2021; **49:** 173.
3. Kim WT, Ham WS, Jeong W et al: Failure and malfunction of da Vinci surgical systems during various robotic surgeries: experience from six departments at a single institute. Urology 2009; **74:** 1234.