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Factors Associated with Stone-Free Outcomes after Flexible Ureteroscopy for Lower Pole Renal Stones: A Comparative Analysis of Flexible and Navigable Suction and Conventional Ureteral Access Sheaths – AUSET collaboration

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Research Article

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Abstract

Purpose

Flexible and navigable suction ureteral access sheaths (FANS) may alter fragment evacuation and potentially reduce the procedural consequences of unfavorable collecting-system geometry especially lower pole. We evaluated factors impacting postoperative stone-free status between FANS and conventional ureteral access sheaths.

Methods

This retrospective multicenter cohort included 214 fURS procedures in 176 patients treated at Kaohsiung Medical University Hospital and Seoul National University Hospital. Of these, 107 procedures used FANS and 107 used a conventional sheath. The primary outcome was stone-free status, defined as no residual calculus ≥ 2 mm approximately 1 month after fURS. The main multivariable logistic regression included sheath technique, cumulative stone size, CT attenuation, IW, RIL, IPA, and PSA. Patient-clustered robust standard errors accounted for repeated procedures. Secondary analyses were angle-by-sheath interaction models and a Korea-only analysis assessed effect modification.

Results

Stone-free status was achieved in 69.2% of FANS procedures and 57.9% of conventional-sheath procedures. In the main adjusted model, larger cumulative stone size was associated with lower stone-free odds (aOR per 1 cm, 0.613; 95% CI, 0.438–0.859; p = 0.004). Higher CT attenuation was also associated with lower odds (aOR per 100 HU, 0.911; 95% CI, 0.849–0.978; p = 0.010). FANS use showed higher adjusted odds (aOR, 1.724; 95% CI, 0.703–4.225; p = 0.234). IW, RIL, IPA, and PSA showed no independent associations. Interaction analyses did not identify sheath-dependent IPA or PSA associations.

Conclusion

Stone size and CT attenuation were the main independent predictors of stone-free outcomes after flexible ureteroscopy for lower pole renal stones. FANS use was associated with a numerically higher likelihood of stone-free status, although this did not reach statistical significance after adjustment. Anatomical lower pole parameters were not independently predictive in this cohort.

Introduction

Flexible ureteroscopy (fURS) is an established treatment for renal calculi across a broad range of stone sizes and locations. Lower-pole stones nevertheless remain challenging because postoperative stone

clearance is determined by the combined effects of stone burden, radiodensity, number and distribution, collecting-system anatomy, and operative strategy [1]. Among these factors, unfavorable lower-pole anatomy can impede endoscopic access, ureteroscope deflection, stone relocation, and fragment clearance [2]. Contemporary European Association of Urology guideline therefore recognizes difficult lower-pole anatomy as a factor associated with reduced success after retrograde intrarenal surgery (RIRS) [1].

The introduction of flexible and navigable suction ureteral access sheaths (FANS) has changed the management of renal stones by allowing active evacuation of stone fragments while maintaining continuous outflow. Emerging evidence suggests that FANS may be particularly advantageous for lower-pole stones, where fragment clearance has traditionally been limited by gravity and unfavorable collecting-system anatomy [3]. Prospective randomized data have also shown improved stone-free outcomes with FANS compared with conventional sheaths in patients with lower calyceal stones [4]. Comparative evidence has likewise supported the effectiveness of FANS for inferior calyceal calculi [5]. These findings raise the possibility that FANS may attenuate some of the procedural consequences of unfavorable lower-pole anatomy. However, whether anatomical parameters such as the infundibulopelvic angle (IPA) and pelvic stone angle (PSA) retain their prognostic value for stone-free outcomes in the setting of FANS remains unclear.

IPA has received considerable attention as a potential anatomical predictor of stone-free outcomes. Dresner et al. identified an association between lower-pole IPA and ureteroscopic success [2], and a subsequent systematic review and meta-analysis supported the relationship between IPA and stone clearance after ureteroscopy [6]. The pelvic stone angle (PSA) was subsequently proposed as a CT-based measurement centred on the lower-pole stone and the ureteropelvic junction. Initial evaluation showed that PSA could be incorporated into established retrograde intrarenal surgery scoring systems, with predictive performance comparable to that of conventional IPA-based models [7]. These findings establish IPA and PSA as clinically plausible anatomical markers, although stone-free status is unlikely to be determined by either measurement in isolation.

The aim of this research is to compare FANS and conventional ureteral access sheaths and evaluated the factors associated with stone-free status after fURS for lower-pole renal stones. We also assessed whether sheath technique modified the effects of IPA and PSA on stone-free outcomes.

Materials and Methods

Study design and population

This retrospective cohort study analysed 214 fURS procedures in 176 patients for renal stones involving the lower pole at Kaohsiung Medical University Hospital (KMUH) and Seoul National University Hospital (SNUH). The study was approved by the institutional review boards of KMUHIRB-E(I)-20260118 and 1901-104-1005. The fixed analytic cohort comprised 74 FANS cases from KMUH, 33 FANS cases from

SNUH, and 107 conventional-sheath cases from SNUH. The cohort structure is shown in Fig. 1. The KMUH study period was June 2024 to September 2025; the SNUH cohort was treated from January 2022 to March 2026. Eligible cases involved adults aged 18 years or older who underwent fURS for at least one calculus in a lower-pole calyx; additional calculi in other calyces were permitted. Cases involving concomitant surgery, pregnancy, a duplicated ureter, or a horseshoe kidney were excluded. Each fURS procedure was the unit of analysis. Repeated eligible procedures in the same patient were retained and linked using a de-identified patient identifier.

Surgical technique and perioperative management

Procedures were performed by experienced endourologists under general anaesthesia with the patient in the lithotomy position. After ureteroscopic inspection and guidewire placement, a ureteral access sheath was advanced according to institutional practice. Cases were classified according to whether a FANS or conventional ureteral access sheaths was used. Stone relocation, laser lithotripsy, basket extraction, and postoperative ureteral stenting were selected according to stone characteristics, intraoperative findings, and surgeon judgement.

Imaging and anatomical measurements

Preoperative non-contrast computed tomography (CT) was reviewed for cumulative stone size, attenuation of the lower-pole stone, infundibular width (IW), renal infundibular length (RIL), infundibulopelvic angle (IPA), and pelvic stone angle (PSA). Cumulative stone size was defined as the sum of the maximal diameters of the relevant renal calculi. CT attenuation was recorded in Hounsfield units (HU). IPA was defined by the infundibular and pelvi-ureteric axes. PSA was measured as previously described: a vertical line was drawn through the lower-pole stone center, and a second line connected the stone center to the midpoint of the ureteropelvic junction; the angle between these lines was recorded as PSA. Two physicians independently measured IPA and PSA while blinded to postoperative stone-free status and sheath type. Angles were analysed as continuous variables and scaled per 10-degree increase. The primary outcome was postoperative stone-free status, defined as no residual calculus ≥ 2 mm on postoperative imaging obtained approximately 1 month after fURS. Postoperative imaging consisted of kidney-ureter-bladder (KUB) radiography or CT according to clinical indication.

Statistical analysis

Continuous variables are reported as mean (standard deviation), and categorical variables as number (percentage). Between-group comparisons used Welch's t-test or Fisher's exact test, as appropriate, and were descriptive. The primary multivariable logistic regression included sheath technique, cumulative stone size (per 1-cm increase), lower-pole CT attenuation (per 100-HU increase), IW, RIL, IPA, and PSA. Conventional sheath use was the reference category. Patient-clustered robust standard errors accounted

for repeated procedures. Adjusted odds ratios (aORs), 95% confidence intervals (CIs), and two-sided p values are reported.

Secondary analyses used separate multivariable logistic regression models for IPA and PSA to avoid placing correlated angles in the same interaction model. Each model included the respective angle, sheath type, the angle-by-sheath interaction, cumulative stone size, CT attenuation, age, sex, body mass index, and center. IPA was centered at 50 degrees and PSA at 40 degrees before constructing the interaction terms. The FANS was the reference category in these models. Sheath-specific angle effects and interaction estimates are presented in Supplementary Table 1(Online Resource 1), and full coefficients in Supplementary Table 2(Online Resource 1).

All interaction models used the fixed cohort of 214 fURS procedures in 176 patients. Standard errors were clustered by patient to account for repeated procedures. Effect modification was assessed using the angle-by-sheath interaction term. The Korea-only analysis included 140 fURS procedures in 116 patients and omitted the centre indicator. All tests were two-sided, with $p < 0.05$ denoting statistical significance. Analyses were performed in R version 4.6.1 (R Foundation for Statistical Computing, Vienna, Austria). Figure 2 displays adjusted probabilities from the full-cohort interaction models with patient-clustered robust 95% CIs.

Results

Cohort characteristics

The fixed analytic cohort comprised 214 fURS procedures in 176 patients: 107 treated with a FANS (74 from Taiwan and 33 from Korea) and 107 treated with a conventional sheath (all from Korea; Table 1). Stone-free status was achieved in 69.2% (74/107) of FANS cases and 57.9% (62/107) of conventional-sheath cases. The FANS group had greater cumulative stone size (2.42 ± 1.50 versus 1.30 ± 1.02 cm), whereas the conventional group had higher CT attenuation (1059.02 ± 467.45 versus 643.65 ± 368.56 HU). IPA and PSA also differed between groups. IPA and PSA were moderately correlated in the full analytic cohort (Pearson r = 0.44), with similar correlations in the FANS (r = 0.51) and conventional (r = 0.52) groups.

Table 1
Characteristics of the fixed analytic cohort by sheath group

Male sex, n (%)	**FANS (n = 107)**	**Conventional (n = 107)**	**p value**
	69 (64.5)	**70 (65.4)**	**1.000**
Age, years	58.87 ± 14.99	56.22 ± 15.25	0.202
Body mass index, kg/m²	24.32 ± 4.34	25.00 ± 3.99	0.233
Preoperative creatinine, mg/dL	1.29 ± 1.71	1.42 ± 2.51	0.672
Preoperative eGFR, mL/min/1.73 m²	73.84 ± 27.99	75.09 ± 28.21	0.745
Left-sided stone, n (%)	66 (61.7)	62 (57.9)	0.676
Cumulative stone size, cm	2.42 ± 1.50	1.30 ± 1.02	< 0.001
Lower-pole stone size, cm	1.30 ± 0.71	1.30 ± 1.02	0.972
Lower-pole attenuation, HU	643.65 ± 368.56	1059.02 ± 467.45	< 0.001
IW, mm	8.33 ± 5.33	10.08 ± 4.55	0.010
RIL, mm	20.88 ± 7.63	24.12 ± 7.25	0.002
IPA, degrees	52.93 ± 16.44	61.40 ± 17.17	< 0.001
PSA, degrees	41.87 ± 11.13	37.27 ± 11.46	0.003
No residual calculus ≥ 2 mm, n (%)	74 (69.2)	62 (57.9)	0.118

Data are mean ± standard deviation unless otherwise indicated. eGFR, estimated glomerular filtration rate; FANS, Flexible and navigable suction ureteral access sheaths; HU, Hounsfield units; IPA, infundibulopelvic angle; IW, infundibular width; PSA, pelvic stone angle; RIL, renal infundibular length. Continuous variables were compared using Welch's t-test and categorical variables using Fisher's exact test. P values are two-sided and descriptive; no adjustment was made for multiple comparisons.

Multivariable factors associated with stone-free status

The main regression was showed in Table 2. FANS use was associated with higher adjusted odds of stone-free status than conventional sheath use (aOR 1.724, 95% CI 0.703–4.225; p = 0.234). Each 1-cm increase in cumulative stone size was associated with lower odds (aOR 0.613, 95% CI 0.438–0.859; p = 0.004). Higher CT attenuation was also associated with lower odds (aOR per 100 HU 0.911, 95% CI 0.849–0.978; p = 0.010). IW, RIL, IPA, and PSA were not independently associated with the outcome.

Table 2
Multivariable logistic regression for stone-free status (< 2 mm)

Variable	Adjusted OR	95% CI	p value
FANS (vs conventional)	1.724	0.703–4.225	0.234
Cumulative stone size (per 1 cm)	0.613	0.438–0.859	0.004
CT attenuation of lower-pole stone (per 100 HU)	0.911	0.849–0.978	0.010
Infundibular width, IW (per 1 mm)	0.994	0.937–1.055	0.838
Renal infundibular length, RIL (per 1 mm)	0.996	0.951–1.043	0.869
Infundibulopelvic angle, IPA (per 1 degree)	0.989	0.968–1.010	0.317
Pelvic stone angle, PSA (per 1 degree)	1.020	0.988–1.053	0.215

Adjusted for sheath technique, cumulative stone size, lower-pole CT attenuation, IW, RIL, IPA, and PSA. Conventional sheath use was the reference category; aOR > 1 favours stone-free status. Standard errors were clustered by patient. CI, confidence interval; FANS, Flexible and navigable suction ureteral access sheaths; HU, Hounsfield units; IPA, infundibulopelvic angle; IW, infundibular width; PSA, pelvic stone angle; RIL, renal infundibular length.

IPA and PSA across sheath types

IPA was not associated with stone-free status within either sheath group (Supplementary Table 1, online Resource 1). Per 10-degree increase, the aOR was 0.90 (95% CI 0.64–1.28; p = 0.567) in the FANS group and 1.09 (95% CI 0.85–1.39; p = 0.509) in the conventional group. The IPA-by-sheath interaction was not statistically significant (interaction aOR 1.20, 95% CI 0.79–1.82; p = 0.389; Fig. 2a). PSA showed no association within either sheath group (Supplementary Table 1, online Resource 1). Per 10-degree increase, the aOR was 1.19 (95% CI 0.74–1.90; p = 0.480) with FANS and 1.15 (95% CI 0.76–1.75; p = 0.510) with a conventional sheath. The PSA-by-sheath interaction estimate was 0.97 (95% CI 0.51–1.83; p = 0.928; Fig. 2b).

Sensitivity analysis

To reduce potential confounding related to differences between treatment centers, the angle-by-sheath interaction analyses were repeated within the SNUH cohort, where both FANS and conventional sheaths were used. This analysis included 140 procedures in 116 patients (33 FANS and 107 conventional-sheath procedures). Neither interaction was statistically significant: the IPA-by-sheath interaction aOR was 1.46 (95% CI, 0.79–2.71; p = 0.226), and the PSA-by-sheath interaction aOR was 1.54 (95% CI, 0.60–3.98; p = 0.373). These results are summarized in Supplementary Table 1(Online Resource 1) and were consistent with the full-cohort interaction analyses.

Discussion

In this retrospective multicenter cohort, cumulative stone size and lower-pole CT attenuation were the strongest independent factors associated with postoperative stone-free status. FANS use was associated with higher adjusted odds, whereas IW, RIL, IPA, and PSA showed no independent association. Secondary analyses also found no evidence that sheath technique modified the associations of IPA or PSA. Together, these findings place stone burden and radiodensity ahead of isolated lower-pole measurements when estimating stone-free outcomes after contemporary fURS.

Lower-pole anatomy has long been considered an important determinant of stone-free outcomes after ureteroscopic treatment; however, our findings suggest that anatomical angles may not be major independent predictors. Dresner et al. reported that lower-pole IPA was associated with success after fURS and laser lithotripsy, and subsequent studies have similarly identified unfavorable IPA and greater stone burden as predictors of residual fragments after RIRS [2, 8]. A 2024 systematic review and meta-analysis further supported an association between IPA and ureteroscopic stone clearance, although the authors emphasized substantial heterogeneity in measurement techniques, stone-free definitions, and proposed angle thresholds, with overall certainty of evidence remaining very low [6]. PSA was subsequently proposed as a CT-based alternative intended to better represent the angle that the flexible ureteroscope must overcome when a ureteral access sheath straightens the ureteral axis. The initial study found PSA-based scoring models to perform comparably with conventional IPA-based models [7]. In a larger subsequent cohort of 198 patients, PSA could again be incorporated into established scoring systems, although overall discrimination remained modest and lower-pole stone burden, stone multiplicity, CT attenuation, and multifocality also contributed substantially to stone-free outcomes [9]. These findings place angular anatomy within a broader, multifactorial framework in which stone characteristics, measurement methods, and procedural context jointly shape RIRS outcomes.

One explanation for the limited prognostic value of preoperative angles is that static radiographic anatomy does not fully represent the functional geometry encountered during contemporary fURS. IPA and PSA describe the anatomical relationship before instrumentation, whereas the relevant surgical environment changes after guidewire placement, access-sheath insertion, ureteroscope deflection, stone manipulation, and stone relocation. In particular, lower-pole stones can be displaced to a more favorable calyx before fragmentation, thereby reducing the requirement for sustained extreme ureteroscope deflection and changing the geometry under which lithotripsy and fragment retrieval are actually performed. Huang et al. demonstrated improved stone-free outcomes with relocation of lower-pole stones compared with treatment in situ, and a subsequent systematic review and meta-analysis similarly found higher stone-free rates with displacement strategies for lower-pole stones < 2 cm [10, 11]. These observations highlight an important distinction between anatomical difficulty and procedural exposure to that difficulty. A patient may have an unfavorable preoperative IPA or PSA, yet the effect of that anatomy on final clearance can be attenuated if operative maneuvers effectively bypass the anatomical constraint. Consequently, a preoperative angle may increasingly function as a marker of anticipated technical difficulty rather than a direct determinant of final stone-free status.

FANS could further modify the procedural consequences of lower-pole anatomy by changing how fragments are cleared from the collecting system. Unlike conventional RIRS, in which clearance depends largely on basket extraction, irrigation, gravity, and subsequent spontaneous passage, suction-assisted systems permit active evacuation of dust and small fragments while maintaining continuous outflow. In an international multicenter randomized trial, Zhu et al. reported higher immediate and 3-month stone-free rates with a FANS than with a conventional sheath, together with lower postoperative fever rates and markedly reduced basket use [12]. Prospective multicenter experience has also demonstrated the feasibility of FANS specifically for lower-pole stones [3], while in-vivo pressure monitoring has shown that relatively low intrarenal pressures can be maintained during fURS using FANS [13]. Complementary prospective data from a 25-centre real-world FANS cohort and a randomized study restricted to 1-2-cm lower calyceal stones also reported favorable early or 1-month clearance with FANS, although differences in comparators and stone-free definitions limit direct comparison across studies [4, 14]. In our cohort, the adjusted technique estimate favoured FANS use and was directionally consistent with those studies. The IPA and PSA interaction analyses showed that this association was not concentrated in a particular angular configuration. FANS therefore appears to influence clearance through mechanisms broader than a measurable change in the prognostic effects of IPA or PSA.

The concept that lower-pole geometry influences clearance has historical roots in anatomical and radiographic studies, initially in shock-wave lithotripsy and subsequently in ureteroscopic treatment [15, 16]. Stone-free status is a multifactorial endpoint determined not only by collecting-system anatomy but also by stone burden, number, distribution, density, operative strategy, and the ability to remove or relocate fragments. Established RIRS prediction tools such as the Resorlu-Unsal Stone Score (RUSS), modified Seoul National University Renal Stone Complexity score, and Ito nomogram likewise combine multiple preoperative characteristics rather than relying on a single angle [17–19]. Comparative and external-validation studies have shown that their discrimination varies across cohorts and that stone burden can outperform a location-only complexity score [20, 21]. Our multivariable results reinforce this hierarchy: stone size and attenuation retained independent associations, whereas IW, RIL, IPA, and PSA did not. IPA and PSA may remain useful for anticipating lower-pole access, ureteroscope deflection, relocation, or procedural complexity rather than final stone-free status.

This study has several limitations. First, this is a retrospective study. Second, sheath type was closely linked to center and treatment period. Although the models adjusted for center, they could not fully separate sheath effects from institutional practices, patient selection, or temporal changes. Third, postoperative stone-free status was assessed using either KUB radiography or CT according to clinical indication. Differences in imaging modality, follow-up timing, and residual-fragment thresholds may have introduced outcome misclassification, particularly at the 2-mm threshold [22, 23]. Fourth, several operative variables, including sheath characteristics, suction settings, laser strategy, operative time, surgeon experience, and intrarenal pressure, could not be harmonised across centers. Finally, formal interobserver reliability was not reported, and the models assumed linear angle effects. Larger prospective within-center studies using standardised imaging, procedural definitions, and angle measurements should confirm these findings and assess nonlinear or subgroup effects.

Conclusion

In this multicenter fURS cohort, cumulative stone size and lower-pole CT attenuation were independently associated with lower stone-free odds. FANS use showed higher adjusted odds, while IW, RIL, IPA, and PSA were not independent predictors. These findings support a multifactorial assessment centered on stone burden and radiodensity, with sheath strategy considered as a procedural contributor.

Declarations

Funding

No funding was received for conducting this study.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics approval

This study was approved by the Institutional Review Board of Kaohsiung Medical University Hospital (KMUHIRB-E(I)-20260118) and the Institutional Review Board of Seoul National University Hospital (1901-104-1005).

Consent to participate

The requirement for informed consent was waived by the respective institutional review boards owing to the retrospective nature of the study.

Data availability

The data supporting the findings of this study are not publicly available due to patient privacy considerations. Access to the data is subject to applicable institutional policies and ethical approvals at the participating institutions.

Author contributions

Chun Kai Chang: Manuscript writing; data management.

Jose Carlo Elises: Manuscript writing; data collection.

Hao Han Chang: Data management.

Jon-Alexis S. Montemayor: Protocol/project development.

Sung Yong Cho: Protocol/project development.

Hsiang Ying Lee: Protocol/project development; manuscript writing/editing.

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Figures

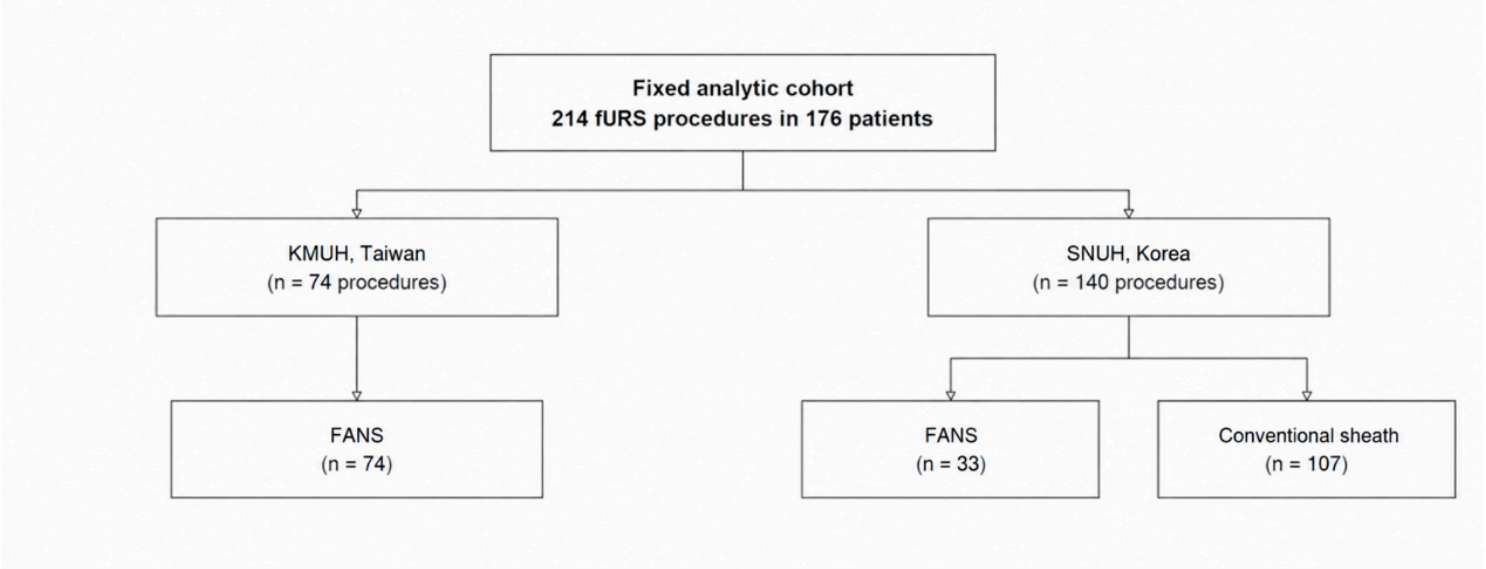


Figure 1

Study cohort composition by centre and ureteral access sheath type

The cohort comprised 214 fURS procedures from 176 patients. KMUH contributed 74 FANS procedures. SNUH contributed 140 procedures, including 33 FANS and 107 conventional-sheath procedures. Counts represent procedures; standard errors in the analyses were clustered by patient to account for repeated procedures. FANS, Flexible and navigable suction ureteral access sheaths;

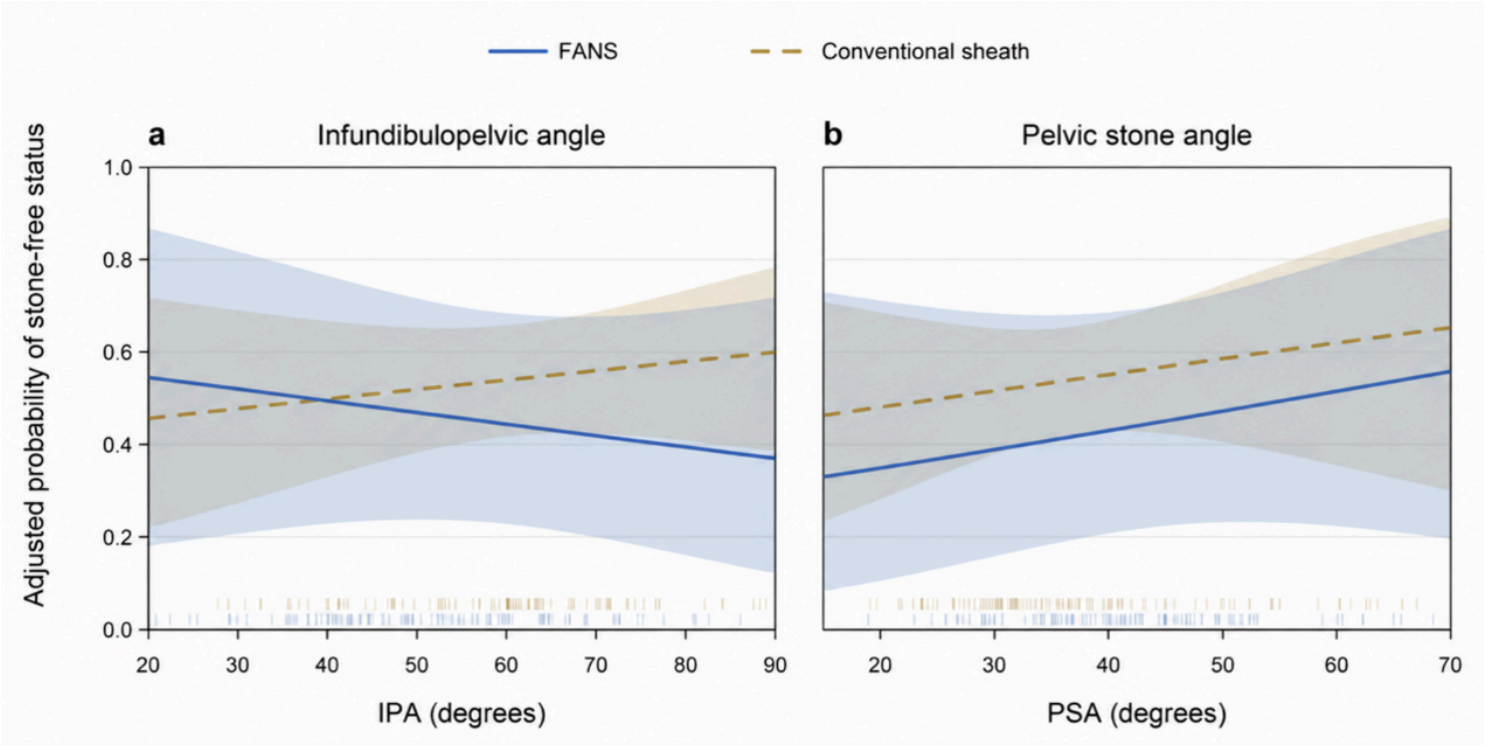


Figure 2

Adjusted associations of lower-pole anatomical angles with stone-free status by sheath type

a, Adjusted probability of stone-free status across the infundibulopelvic angle (IPA). b, Adjusted probability of stone-free status across the pelvic stone angle (PSA). Lines show model-based estimates and shaded bands indicate patient-clustered robust 95% confidence intervals; staggered rug marks along the lower margin show the observed procedure-level angle values for the FANS and conventional-sheath groups; continuous covariates were fixed at their means, sex at the observed proportion, and centre at SNUH. The IPA-by-sheath interaction was not statistically significant (adjusted odds ratio [aOR] 1.20 per 10 degrees, 95% confidence interval [CI] 0.79-1.82; p=0.389), nor was the PSA-by-sheath interaction (aOR 0.97 per 10 degrees, 95% CI 0.51-1.83; p=0.928). FANS, Flexible and navigable suction ureteral access sheaths.

Supplementary Files

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- Supplementary.pdf