

Maximum Stone-Edge Angle (MSEA): A Novel Approach for Predicting Retrograde Intrarenal Surgery Success in Patients with a Single Lower Pole Stone

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Abstract

Background

Lower pole kidney stones remain challenging to treat with retrograde intrarenal surgery because of unfavorable pelvicalyceal anatomy. Several angle measurements were proposed to quantify this complexity, but they are not fully standardized and show inconsistent predictive value. Additionally, these measurements do not reflect the maximum deflection of the flexible ureteroscope required to reach the entire stone, an important technical challenge during surgery. To address this limitation, we introduced the maximum stone-edge angle (MSEA), assessed its predictive value, and compared it with existing angle measurements.

Methods

We retrospectively reviewed 116 patients who underwent retrograde intrarenal surgery for a single lower pole stone ≤ 2 cm between January 2023 and March 2026. Computed tomography was used to measure the infundibulopelvic angle, pelvic stone angle, MSEA, infundibular length and width, stone length, volume and density. Stone-free status was defined as no or ≤ 2 mm residual stone. Continuous variables were compared using the independent-samples t test or Mann–Whitney U test, and categorical variables using Pearson's chi-square test. Discriminative ability was assessed using ROC analysis, and an optimal cut-off value was determined when significant. Univariable and multivariable binary logistic regression analyses were performed to identify predictors of stone-free status.

Results

Stone-free status was achieved in 76 of 116 patients (65.5%). MSEA was significantly higher in stone-free than non-stone-free patients (29.25° vs 24.50° , $p < 0.001$), while infundibulopelvic and pelvic stone angles did not differ significantly. MSEA showed significant discrimination for stone-free status (AUC 0.725, 95% CI 0.614–0.836; $p < 0.001$). The optimal cut-off was 25.75° , with 81.6% sensitivity and 65.0% specificity. In multivariable models, $\text{MSEA} \geq 25.75^\circ$ independently increased the likelihood of stone-free status when stone burden was represented by maximum stone length (OR 9.641, 95% CI 3.483–26.688; $p < 0.001$) or stone volume (OR 9.107, 95% CI 3.486–23.790; $p < 0.001$). Greater maximum stone length and stone volume were each independently associated with a lower likelihood of stone-free status in separate models.

Conclusions

MSEA may provide a simple, stone-oriented anatomical measure that better reflects the deflection required to access the entire lower pole stone than conventional angle measurements. Further validation

and reproducibility assessment may support its future clinical use.

Introduction

Kidney stone disease is a common condition associated with genetic, environmental, and metabolic factors [1, 2]. Its prevalence has increased worldwide in recent years and has been reported to reach 18.5% in some high risk populations [2]. Its chronic and recurrent nature makes long term management challenging [3, 4]. Lower pole kidney stones are commonly investigated in clinical studies because they can be more challenging to access and treat [5–7]. Extracorporeal shock wave lithotripsy (SWL), retrograde intrarenal surgery (RIRS), and percutaneous nephrolithotomy (PCNL) are currently used for lower pole kidney stones, and their outcomes are often compared [5, 7–9].

Treatment outcomes for lower pole kidney stones are influenced by stone characteristics such as size, volume, and density, as well as morphometric parameters, including the infundibulopelvic angle (IPA), infundibular length (IL), and infundibular width (IW) [6, 10–14]. However, there is no clear consensus on how some of these parameters should be measured or how much they affect treatment outcomes [15, 16]. Different methods have been developed over the years to calculate stone volume or measure IPA [17–21]. The conventional IPA is usually measured as the inner angle between the ureteropelvic axis and the central axis of the lower pole infundibulum [5, 20, 21]. The more recently introduced pelvic stone angle (PSA) uses a vertical reference line because the ureteral access sheath straightens the ureteral axis during RIRS. It was defined as the angle between this line, passing through the center of the lower pole stone, and a second line drawn from the stone center to the midpoint of the ureteropelvic junction [22].

Both conventional and newer IPA measurements evaluated as predictors of RIRS success for lower pole stones [5, 6, 22]. Yet, an angle that directly measures the maximum deflection required of the flexible ureteroscope (fURS) to reach the entire stone remains lacking. Moreover, achieving and maintaining maximum deflection during RIRS is one of the most challenging aspects of treating lower pole stones. In this study, we defined the maximum stone-edge angle (MSEA) to estimate the maximum deflection required for the fURS to reach and treat the entire lower pole stone and assessed its relationship with treatment success.

Methods

We retrospectively reviewed 116 patients who underwent retrograde intrarenal surgery for a single lower pole stone ≤ 2 cm between January 2023 and March 2026 to evaluate the predictive value of MSEA and compare it with existing angle measurements. Patients with a single lower pole stone measuring up to 2 cm in maximum length were included; those with renal anatomical abnormalities or incomplete clinical records were excluded. After applying the criteria, 116 patients were included in the final analysis. All procedures were performed by two teaching urologists, each with at least 5 years of experience in RIRS. In all cases, a 9.5 Fr single use ureteral access sheath (Flexor, Cook Medical), a 7.5 Fr single use fURS

(HU30S, HugeMed), and a holmium–yttrium–aluminum–garnet (Ho:YAG) laser with a 272 μm fiber were used. At the end of the procedure, a double-J ureteral stent was placed in all patients.

Preoperative non-contrast computed tomography (CT) images were reviewed together in the axial, coronal, and sagittal planes. The longest stone diameter seen in any of these planes was recorded as length (L). The largest diameter at 90° to L was recorded as width (W). The third orthogonal diameter was recorded as height (H). Stone volume was calculated using the ellipsoid formula: $\pi/6 \times L \times W \times H$. The presence of residual stones was assessed using operative notes, kidney ureter bladder (KUB) radiographs, and non-contrast CT. KUB radiographs were routinely obtained on postoperative day 1 in all patients. Additional non-contrast CT was performed at 1 month in patients with residual stones noted in the operative report or with ongoing suspicion of residual stones. Patients were classified into four groups according to residual stone size: no residual stone, residual stone ≤ 2 mm, residual stone > 2 to ≤ 4 mm, and residual stone > 4 mm. Stone-free (SF) status was defined as no residual stone or a residual stone ≤ 2 mm.

All morphometric measurements were performed by a single investigator on preoperative non-contrast coronal CT images using Sectra UniView (Sectra AB). Infundibular length (IL) was measured from the most distal point of the stone bearing calyx to the midpoint of its opening into the renal pelvis. Infundibular width (IW) was measured at the narrowest point of the infundibulum. IPA was defined as the inner angle between the ureteropelvic axis and the central axis of the lower pole infundibulum. The ureteropelvic axis was drawn from the midpoint of the renal pelvis to the central point of the ureter at the level of the lower pole. For PSA measurement, a vertical reference line passing through the center of the lower pole stone was used. A second line was drawn from the stone center to the midpoint between the highest and lowest points of the ureteropelvic junction, and the angle between these two lines was recorded as the PSA. MSEA was measured using the same vertical reference line and ureteropelvic junction midpoint. However, instead of the stone center, the line was drawn from the stone edge to require the greatest fURS deflection to reach and treat the entire stone. The angle between this line and the vertical reference line was recorded as the MSEA (Figs. 1 and 2).

The distribution of continuous variables was assessed separately in the SF and non-SF groups using the Shapiro Wilk test. Normally distributed variables were presented as mean $\pm$ standard deviation and compared using the independent samples t-test. Non-normally distributed variables were presented as median (minimum–maximum) and compared using the Mann Whitney U test. Categorical variables were presented as n (%) and compared using Pearson's chi-square test. The ability of IPA, PSA, and MSEA to distinguish SF outcomes was evaluated using receiver operating characteristic (ROC) curve analysis. The area under the curve (AUC), 95% confidence interval, and p value were calculated. For variables with statistically significant discriminative ability, the optimal cut-off value was determined using the Youden index. The association between each category and SF outcome was evaluated using univariable binary logistic regression analysis. Two separate multivariable binary logistic regression model sets were constructed. Both model sets included the ROC derived MSEA cut-off category, stone density, and sex. The first model set additionally included maximum stone length, whereas the second included calculated

stone volume. Maximum stone length and stone volume were not entered into the same model because they represented alternative measures of stone burden. For each model set, a full model was constructed using the Enter method. A separate Backward likelihood ratio (LR) analysis was then performed to obtain a reduced final model. Results were presented as odds ratios with 95% confidence intervals and p values. Overall model significance was evaluated using the Omnibus test, model calibration using the Hosmer Lemeshow test, and explanatory ability using the Nagelkerke R² value. Overall classification accuracy was also reported.

Statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp.). Relevant figures were generated using Python version 3.14 (Python Software Foundation). A p value < 0.05 was considered statistically significant.

Results

The patients' age was 50.76 ± 13.52 years (23–78). Sixty patients (51.7%) were male and 56 (48.3%) were female. The stone was left-sided in 62 patients (53.4%) and right-sided in 54 (46.6%). The stone length was 14.03 ± 3.57 mm (5–20), width was 10.61 ± 3.08 mm (4–18), height was 10.00 mm (5–16), and volume was 878.34 mm^3 (52.36–1851.45). Stone density was 1007.37 ± 343.18 Hounsfield unit (HU) (249–1753). IPA was $51.77 \pm 14.75^\circ$ (22.7–84.4), PSA was 38.50° (24.7–72.4), and MSEA was 27.65° (17.7–58.5). IL was 23.66 ± 3.92 mm (14–34), IW was 6.00 mm (4–10), and operative time was 70.00 minutes (40–120). Residual stone size was 0 mm in 41 patients (35.3%), ≤ 2 mm in 35 (30.2%), > 2 to ≤ 4 mm in 19 (16.4%), and > 4 mm in 21 (18.1%). Accordingly, 76 patients (65.5%) were SF, while 40 (34.5%) were not SF.

Significant differences were found between the non-SF and SF groups in maximum stone length (16.18 ± 2.32 vs. 12.91 ± 3.61 mm, $p < 0.001$), stone width (11.58 ± 2.83 vs. 10.11 ± 3.11 mm, $p = 0.014$), stone volume (1042.49 [395.84–1735.73] vs. 744.56 [52.36–1851.45] mm^3 , $p < 0.001$), and MSEA (24.50° [17.7–53.0] vs. 29.25° [19.5–58.5], $p < 0.001$), respectively. There were no significant differences between the non-SF and SF groups in age (53.55 ± 14.67 vs. 49.29 ± 12.73 years, $p = 0.107$), stone density (1081.35 ± 293.14 vs. 968.43 ± 362.55 HU, $p = 0.092$), IPA ($49.21 \pm 15.20^\circ$ vs. $53.11 \pm 14.42^\circ$, $p = 0.176$), IL (23.50 ± 4.06 vs. 23.74 ± 3.87 mm, $p = 0.759$), stone height (11.00 [7–16] vs. 10.00 [5–16] mm, $p = 0.062$), PSA (35.65° [24.7–72.4] vs. 41.05° [25.7–71.3], $p = 0.135$), IW (7.00 [4–10] vs. 6.00 [4–10] mm, $p = 0.336$), or operation time (80.00 [40–120] vs. 70.00 [40–120] minutes, $p = 0.142$), respectively. Among the 40 non-SF patients, 22 (55.0%) were male and 18 (45.0%) were female; among the 76 SF patients, 38 (50.0%) were male and 38 (50.0%) were female. There was no significant association between sex and SF status ($p = 0.608$). Among the 40 non-SF patients, stones were located on the left side in 17 (42.5%) and on the right side in 23 (57.5%) and among the 76 SF patients, stones were located on the left side in 45 (59.2%) and on the right side in 31 (40.8%). There was no significant association between stone side and SF status ($p = 0.086$) (**Table 1**).

According to the ROC analysis, the discriminative ability of IPA for predicting SF status was not statistically significant (AUC=0.603, 95% CI: 0.491–0.715, $p=0.069$). Similarly, PSA did not show significant discriminative ability for predicting SF status (AUC=0.585, 95% CI: 0.472–0.697, $p=0.135$). In contrast, MSEA had significant discriminative ability for predicting SF status (AUC=0.725, 95% CI: 0.614–0.836, $p<0.001$) (**Figure 3**). The optimal cut-off value was 25.75° , with a sensitivity of 81.6% and a specificity of 65.0% (**Table 2**). An MSEA of $\geq 25.75^\circ$ was significantly associated with a SF outcome compared with an MSEA of $<25.75^\circ$ (OR=8.224, 95% CI: 3.443–19.649, $p<0.001$). The multivariable logistic regression model including MSEA category ($\geq 25.75^\circ$ vs. $<25.75^\circ$), maximum stone length, stone density, and sex was statistically significant overall (Omnibus $\chi^2=47.628$, $p<0.001$). An MSEA of $\geq 25.75^\circ$ independently increased the likelihood of a SF outcome (OR=9.641, 95% CI: 3.483–26.688, $p<0.001$), while each 1 mm increase in maximum stone diameter decreased this likelihood (OR=0.702, 95% CI: 0.587–0.839, $p<0.001$). Stone density and sex were not independently significant. The model had an overall classification accuracy of 78.4%, a Nagelkerke R^2 of 0.465, and a Hosmer Lemeshow test p value of 0.743. The multivariable logistic regression model, in which stone volume was used instead of maximum stone diameter while MSEA category ($\geq 25.75^\circ$ vs. $<25.75^\circ$), stone density, and sex remained unchanged, was also statistically significant overall (Omnibus $\chi^2=38.834$, $p<0.001$). An MSEA of $\geq 25.75^\circ$ independently increased the likelihood of a SF outcome (OR=9.107, 95% CI: 3.486–23.790, $p<0.001$), while increasing stone volume was independently associated with a lower likelihood of a SF outcome (OR=0.998, 95% CI: 0.997–0.999, $p=0.002$). Stone density and sex were also not independently significant in this model (**Table 3**). The model had an overall classification accuracy of 79.3%, a Nagelkerke R^2 of 0.393, and a Hosmer Lemeshow test p value of 0.376. The model using maximum stone length had slightly greater explanatory power (Nagelkerke R^2 : 0.465 vs. 0.393), while the model using stone volume had a marginally higher overall classification accuracy (79.3% vs. 78.4%).

In the Backward LR analysis, stone density and sex were removed from the model including maximum stone length. The final model was statistically significant overall (Omnibus $\chi^2=47.510$, $p<0.001$). In this model, an MSEA of $\geq 25.75^\circ$ increased the likelihood of a SF outcome (OR=9.510, 95% CI: 3.456–26.173, $p<0.001$), while increasing maximum stone length was associated with a lower likelihood of a SF outcome (OR=0.700, 95% CI: 0.588–0.832, $p<0.001$). The final model had a Nagelkerke R^2 of 0.464, a Hosmer Lemeshow test p value of 0.640, and an overall classification accuracy of 80.2%. In the Backward LR analysis of the model including stone volume, stone density and sex were also removed. The final model was statistically significant overall (Omnibus $\chi^2=37.929$, $p<0.001$). An MSEA of $\geq 25.75^\circ$ increased the likelihood of a SF outcome (OR=8.810, 95% CI: 3.408–22.771, $p<0.001$), while increasing stone volume was associated with a lower likelihood of a SF outcome (OR=0.998, 95% CI: 0.997–0.999, $p=0.001$). The model had a Nagelkerke R^2 of 0.385, a Hosmer Lemeshow test p value of 0.558, and an overall classification accuracy of 81.0%.

An MSEA of $\geq 25.75^\circ$ was independently associated with a SF outcome in both final models. Increasing maximum stone length and stone volume were each associated with a lower likelihood of a SF outcome.

Discussion

The present study demonstrates that MSEA and stone burden are associated with SF outcomes after RIRS. Among the three measurements evaluated, MSEA was the only parameter that consistently distinguished SF from non-SF patients and showed significant discriminative ability. An MSEA $\geq 25,75^\circ$ was associated with higher odds of achieving an SF outcome. In contrast, neither conventional IPA nor PSA showed significant discrimination. Greater stone length and stone volume were independently associated with a lower likelihood of achieving SF status. These findings suggest that MSEA may provide a more clinically relevant representation of lower pole anatomy by reflecting the maximum fURS deflection required to access the entire stone.

The importance of pelvicalyceal anatomy in lower pole stone treatment has been recognized before. Although Sampaio[23] and Elbahnasy et al.[20] used somewhat different approaches to measure IPA, both found that a wider angle was associated with better stone clearance after SWL. The importance of IPA and variations in its measurement have also been discussed in the contemporary RIRS literature. A recent review of 27 randomized studies involving RIRS found that only four of them directly compared morphometric parameters such as IPA, IL, and IW. The review also showed the lack of standardized measurement methods, particularly for IPA, which may contribute to heterogeneity and limit comparability in the studies [24].

Across RIRS studies, the predictive role of anatomical parameters has shown variable results. Advances in flexible ureteroscopes, laser fibers, and deflection mechanisms may have reduced the effect of unfavorable anatomy on endoscopic access. Karim et al. reported that a steep IPA, particularly $< 30^\circ$, was an important predictor of failure in patients undergoing RIRS for lower pole stones, while IL and IW were less consistently associated with outcome [6]. Tastemur et al., in a cohort of 168 patients with isolated lower pole stones, similarly found a significantly larger IPA in successful than unsuccessful cases and identified an IPA $< 42.65^\circ$ as an independent risk factor for RIRS failure [19]. In a systematic review of 13 studies, Leighton et al. suggested that IPA values $< 30^\circ$ were associated with a particularly low likelihood of SF status and that outcomes were most favorable at angles $> 50^\circ$. However, the authors rated the certainty of evidence as very low because of substantial variation in IPA measurement and SF definitions [21]. Another article also highlighted the lack of standardization in IPA measurement, particularly in terms of methodology, imaging modalities, and interobserver variability [5]. These issues may partly explain why the prognostic value and proposed cut-offs for IPA vary considerably across studies. In our cohort, IPA followed the expected numerical direction, being larger in SF patients, but neither the group difference nor its ROC discrimination reached statistical significance. Our findings still support the importance of lower pole angle. In contrast, conventional IPA may not provide sufficient discrimination in modern RIRS cohorts.

The search for measurements that better represent the actual endoscopic trajectory has gained interest. Tung et al. proposed the PSA, replacing the conventional ureteropelvic axis with a reference intended to reproduce the direction of the ureter after placement of a ureteral access sheath [22]. Their rationale was that the access sheath may straighten the ureter and thereby make conventional preoperative IPA measurements less representative of the geometry encountered during RIRS. When PSA was substituted

for IPA within the R.I.R.S. and Resorlu-Unsal Stone Score (RUS) scoring systems, the resulting models showed predictive performance comparable to that of the original IPA based models. However, PSA itself did not differ significantly between SF and non-SF patients in their cohort. Similarly, Guliev et al. developed the InsKid approach to address the limitations of fixed anatomical axes, using three-dimensional reconstruction of the collecting system to imitate the intraoperative movement of a flexible ureteroscope [15]. In their pilot study, InsKid showed greater discrimination for immediate SF status after RIRS than the conventional methods. The authors suggested that simulating instrument movement may better reflect intraoperative anatomy than fixed central axes. Our findings appear to follow this recent concept. PSA, which is centered on the stone but still represents a single trajectory to its center, showed limited discrimination in the present cohort, whereas MSEA demonstrated an AUC of 0.725. The distinction may be relevant because successful treatment requires more than simply reaching the lower pole calyx or the center of the stone. Adequate endoscopic access must permit effective manipulation and laser application across the stone, including its least accessible margin. By including the stone edge requiring maximum deflection, MSEA may better reflect stone access than IPA or PSA.

Stone burden was the other consistent determinant of treatment outcome in our study. Maximum stone length and volume were greater in non-SF patients, and they remained independently associated with outcome when evaluated in alternative multivariable models. This agrees with previous lower pole RIRS studies. Tastemur et al. reported that increasing stone burden strongly predicted failure [19]. Karim et al. similarly found larger stone size in non-SF patients and noted that increasing stone size adversely affected RIRS success [6]. Kayar et al. identified stone volume as one of the strongest predictors of residual stones and reported greater discrimination for volume than for maximum stone size in their cohort [13]. Our findings are consistent with these studies and further support stone burden as an important determinant of SF outcomes after lower pole RIRS. Both maximum stone length and stone volume remained independently associated with treatment outcome in our cohort.

The absence of significant associations for IL and IW in our cohort also reflects the inconsistent findings in the literature. Karim et al. found neither parameter to influence treatment outcomes, but Morais et al. summarized reports suggesting that a long IL and narrow IW may be associated with lower success [6, 12]. This inconsistency may be related to the complex three dimensional structure of the collecting system, which cannot be fully characterized by a single length, width or angle. The significance of MSEA in the present study may therefore lie not in replacing the broader concept of pelvicalyceal anatomy, but in providing a potentially more function oriented measurement. A systematic review and meta-analysis by Özman et al. evaluated several scoring systems for predicting SF status after RIRS, including the RUS, R.I.R.S., S-ReSC, and S.T.O.N.E. scores [11]. These scoring systems use different stone related and anatomical parameters to predict SF status. Considerable variation was observed and no scoring system showed clearly superior predictive performance. In this context, our findings suggest that MSEA may be a useful parameter for predicting RIRS success and could potentially contribute to future scoring systems.

Several aspects of the present study support the potential predictive value of MSEA. IPA, PSA and MSEA were evaluated within the same patient population. This allowed a direct comparison within the same patient population, without differences in patient selection, imaging, or outcome assessment. In addition, the association between MSEA and SF status remained stable when stone burden was represented either by maximum length or by volume. Non-contributory variables were removed in the final Backward LR models without materially reducing model performance. Nevertheless, the results should be interpreted in light of important limitations. The cohort was relatively modest, particularly with only 40 non-SF outcomes, which limits the precision and generalizability of multivariable estimates. The 25.75° cut-off was derived and evaluated in the same dataset; an external validation is required before it can be used as a clinical decision threshold. Finally, any two dimensional angle measurement simplifies the complex three dimensional pelvicalyceal system, and a new measurement must be reproducible before it can be widely used in clinical practice.

Conclusion

The present findings support previous evidence that kidney anatomy and stone burden influence RIRS outcomes. Conventional IPA and the more recently proposed PSA showed limited discrimination in this cohort, whereas MSEA was consistently associated with SF status and remained an independent predictor after adjustment for stone burden. Increasing maximum stone length and stone volume also reduced the likelihood of SF status. These results suggest that MSEA may be a useful stone oriented anatomical parameter for predicting SF status after RIRS and should be further evaluated.

Abbreviations

AUC: area under the curve

CI: confidence interval

CT: computed tomography

fURS: flexible ureteroscope

Ho:YAG: holmium–yttrium–aluminum–garnet

HU: Hounsfield unit

IL: infundibular length

IPA: infundibulopelvic angle

IW: infundibular width

KUB: kidney ureter bladder

LR: likelihood ratio

MSEA: maximum stone-edge angle

OR: odds ratio

PCNL: percutaneous nephrolithotomy

PSA: pelvic stone angle

R.I.R.S.: renal stone density, inferior pole stone, renal infundibular length, and stone burden scoring system

RIRS: retrograde intrarenal surgery

ROC: receiver operating characteristic

RUS: Resorlu-Unsal Stone Score

SD: standard deviation

SF: stone-free

S-ReSC: modified Seoul National University Renal Stone Complexity Score

S.T.O.N.E.: stone size, topography, obstruction, number, and evaluation of Hounsfield units

SWL: shock wave lithotripsy

Declarations

Ethics approval and consent to participate

Ethics committee approval was obtained from the Manisa Celal Bayar University Faculty of Medicine Health Sciences Ethics Committee (approval date: 1 April 2026; decision no.: 20.478.486/4031). Written informed consent was obtained from all patients.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article and its Supplementary Information files

Competing interests

The authors declare that they have no competing interests

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No funding was received for this study.

Authors' contributions

O.E., O.U., and G.T. conceived and designed the study. A.C.A., İ.C., and A.Y. contributed to patient recruitment, data collection, data curation, and literature review. O.E. performed the CT measurements, prepared the visualizations, and drafted the manuscript. O.E. and G.T. performed the statistical analyses. O.U. and T.M. performed the surgical procedures. İ.C. and T.M. validated the data and study findings. G.T. coordinated and supervised the study together with O.U. and T.M., and T.M. reviewed and edited the manuscript. All authors reviewed and approved the final version of the manuscript. They also agreed to be accountable for their contributions and the integrity of the work.

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Clinical trial number

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Tables

Table 1. Demographic, clinical, and anatomical characteristics of patients according to SF status

Variable	Overall (n=116)	Not stone-free (n=40)	Stone-free (n=76)	p
Age (years), mean $\pm$ SD	50.76 $\pm$ 13.52	53.55 $\pm$ 14.67	49.29 $\pm$ 12.73	0.107 χ^2
Sex, n (%)				0.608 χ^2
Male	60 (51.7)	22 (55.0)	38 (50.0)	
Female	56 (48.3)	18 (45.0)	38 (50.0)	
Stone side, n (%)				0.086 χ^2
Left	62 (53.4)	17 (42.5)	45 (59.2)	
Right	54 (46.6)	23 (57.5)	31 (40.8)	
Stone length (mm), mean $\pm$ SD	14.03 $\pm$ 3.57	16.18 $\pm$ 2.32	12.91 $\pm$ 3.61	<0.001 χ^2
Stone width (mm), mean $\pm$ SD	10.61 $\pm$ 3.08	11.58 $\pm$ 2.83	10.11 $\pm$ 3.11	0.014 χ^2
Stone height (mm), median (min–max)	10.00 (5–16)	11.00 (7–16)	10.00 (5–16)	0.062 χ^2
Stone volume (mm ³), median (min–max)	878.34 (52.36–1851.45)	1042.49 (395.84–1735.73)	744.56 (52.36–1851.45)	<0.001 χ^2
Stone density (HU), mean $\pm$ SD	1007.37 $\pm$ 343.18	1081.35 $\pm$ 293.14	968.43 $\pm$ 362.55	0.092 χ^2
IPA (°), mean $\pm$ SD	51.77 $\pm$ 14.75	49.21 $\pm$ 15.20	53.11 $\pm$ 14.42	0.176 χ^2
PSA (°), median (min–max)	38.50 (24.7–72.4)	35.65 (24.7–72.4)	41.05 (25.7–71.3)	0.135 χ^2
MSEA (°), median (min–max)	27.65 (17.7–58.5)	24.50 (17.7–53.0)	29.25 (19.5–58.5)	<0.001 χ^2
IL (mm), mean $\pm$ SD	23.66 $\pm$ 3.92	23.50 $\pm$ 4.06	23.74 $\pm$ 3.87	0.759 χ^2
IW (mm), median (min–max)	6.00 (4–10)	7.00 (4–10)	6.00 (4–10)	0.336 χ^2
Operation time (min), median (min–max)	70.00 (40–120)	80.00 (40–120)	70.00 (40–120)	0.142 χ^2

Data are presented as mean $\pm$ standard deviation, median (minimum–maximum), or n (%), as appropriate.

IPA: infundibulopelvic angle, PSA: pelvic stone angle, MSEA: maximum stone-edge angle,

IL: infundibular length, IW: infundibular width, HU: Hounsfield unit.

χ^2 : Independent-samples t test, χ^2 : Mann–Whitney U test, χ^2 : Pearson chi-square test.

Table 2. ROC analysis of angles for predicting SF status

	IPA (°)	PSA (°)	MSEA (°)
AUC	0,603	0,585	0,725
95% CI	0.491–0.715	0.472–0.697	0.614–0.836
p	0.069	0.135	<0.001
Optimal cut-off (sensitivity; specificity)	—	—	25.75° (81.6%; 65.0%)

AUC: area under the curve, CI: confidence interval, IPA: infundibulopelvic angle, PSA: pelvic stone angle, MSEA: maximum stone-edge angle.

Table 3. Multivariable logistic regression models for predicting SF status

	Maximum stone length model		Stone volume model	
	OR (95% CI)	p	OR (95% CI)	p
MSEA	9.641 (3.483–26.688)	<0.001	9.107 (3.486–23.790)	<0.001
Maximum stone length (mm)	0.702 (0.587–0.839)	<0.001	—	—
Stone volume (mm³)	—	—	0.998 (0.997–0.999)	0.002
Stone density (HU)	1.000 (0.998–1.001)	0.921	1.000 (0.998–1.002)	0.986
Sex	1.172 (0.440–3.122)	0.751	1.572 (0.603–4.103)	0.355

OR: odds ratio; CI: confidence interval; MSEA: maximum stone-edge angle; HU: Hounsfield unit. Male was the reference category for sex.

Figures

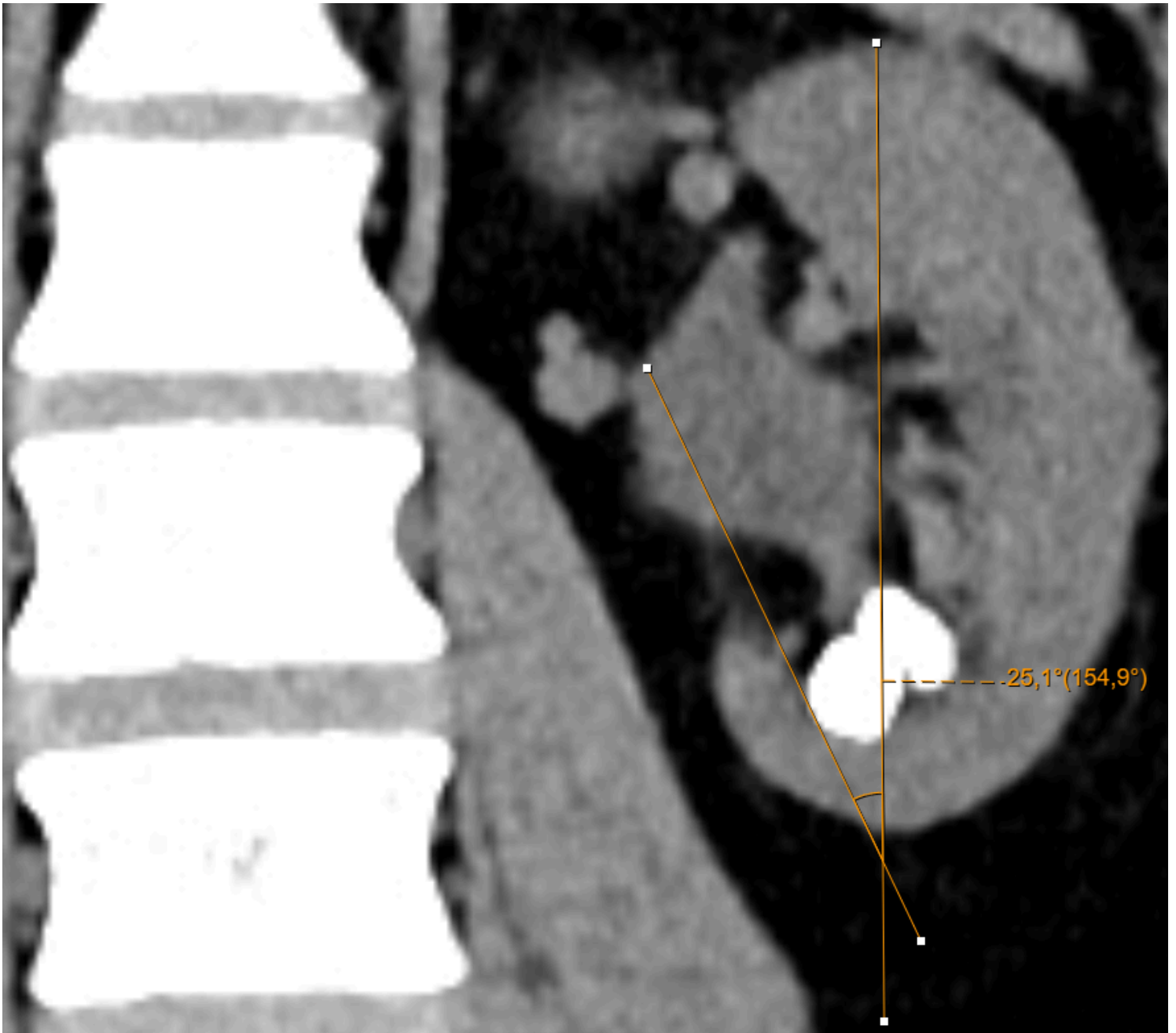


Figure 1

Representative image from a patient included in the study demonstrating measurement of the MSEA

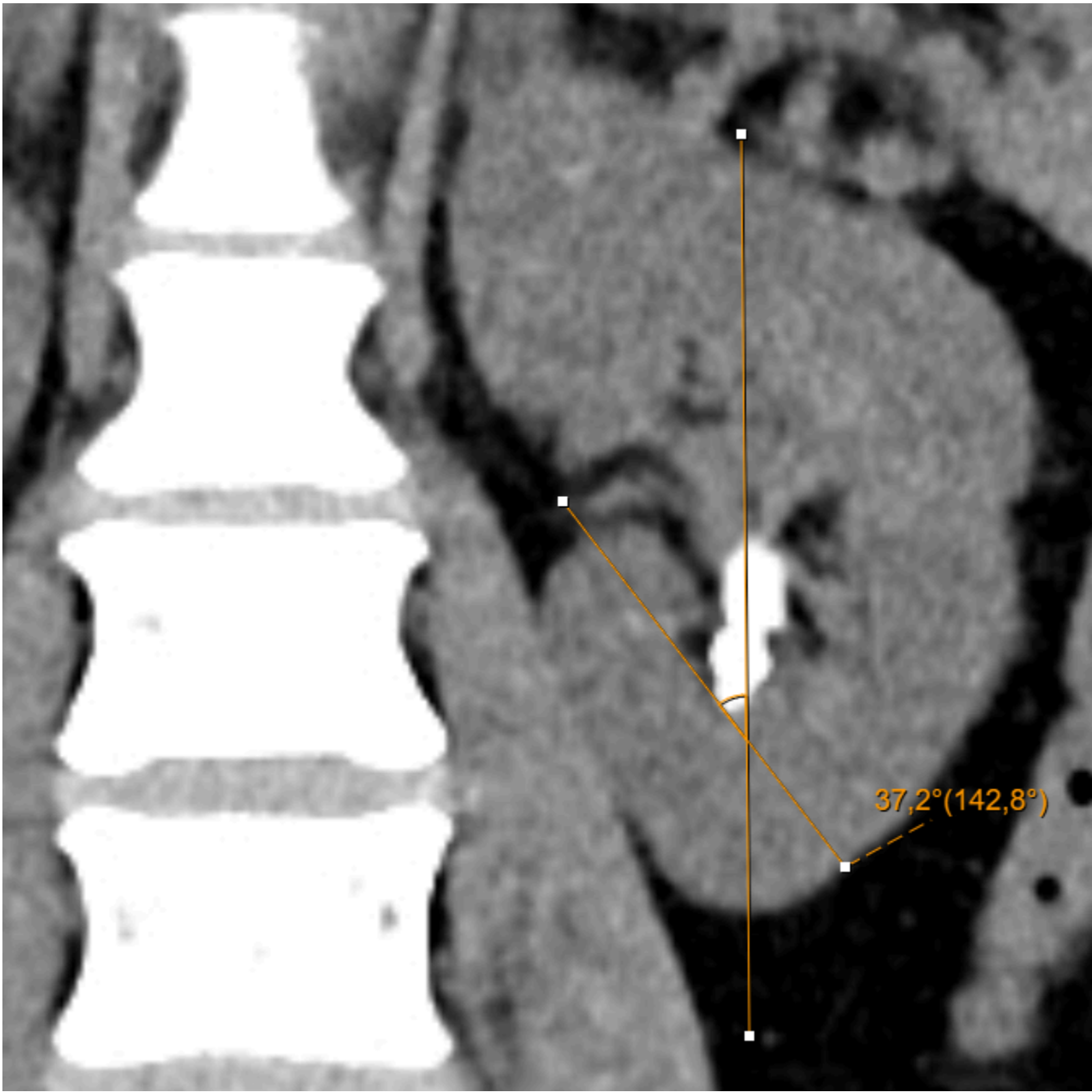


Figure 2

Representative image from another patient included in the study demonstrating measurement of the MSEA

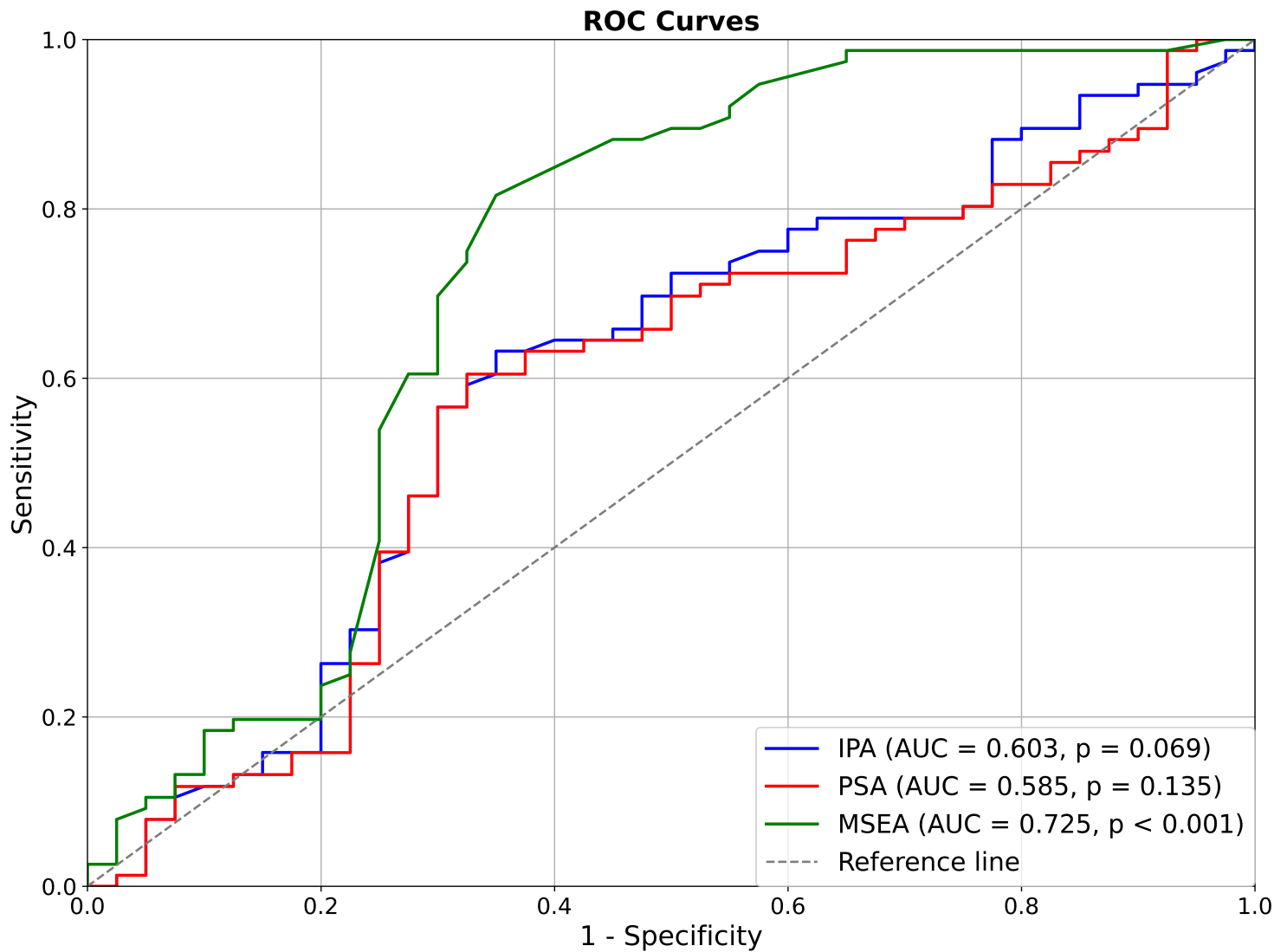


Figure 3

Comparison of ROC curves for IPA, PSA, and MSEA in predicting SF status

IPA: infundibulopelvic angle, PSA: pelvic stone angle, MSEA: maximum stone-edge angle, AUC: area under the curve.

Supplementary Files

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- [AllLowerPole.pdf](#)