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The ratio of perirenal fat thickness to renal parenchymal thickness, a novel indicator of fat accumulation associated with kidney stones

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Abstract

Background Metabolic syndrome, identified by increased visceral fat accumulation, is notably linked to a heightened risk of nephrolithiasis. Despite this, the influence of the perirenal fat thickness relative to renal parenchymal thickness on kidney stones (KS) development remains ambiguous. This study investigated the clinical characteristics of perirenal fat on both the left and right sides and explored the association between the aforementioned ratio and KS.

Methods The study enrolled 161 participants who underwent computed tomography (CT) scans. In this study, kidneys were segregated into two categories based on the presence of stones: stone-bearing and non-stone-bearing for both the left and right kidneys. Perirenal fat parameters were extracted from the imaging workstation database. Both univariate and multivariate logistic regression analyses were conducted to explore the correlation between metrics related to perirenal fat and the occurrence of KS.

Results Among the 161 participants, significant variations in perirenal fat were observed between the left and right kidneys, as well as between genders. Subsequent to adjustments for several confounding variables, the multivariable logistic regression model demonstrated a significant correlation between the ratio of perirenal fat thickness to renal parenchymal thickness and stone bearing kidney ($P < 0.001$).

Conclusions The ratio of perirenal fat thickness to renal parenchymal thickness was significantly correlated with kidney stones.

Keywords Kidney stones, Obesity, Visceral adipose tissue, Receiver operating characteristic

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Introduction

Kidney stones (KS) are a prevalent urological issue, with global incidence rates noted between 7.2% and 7.7%, and an even higher rate of approximately 7.8% in China [1, 2]. There has been a notable rise in both the incidence and prevalence of KS across both sexes, posing a considerable health challenge worldwide [3]. Obesity is recognized as a primary contributor to kidney stone formation [4, 5]. The primary metric for evaluating obesity is body mass index (BMI). However, the effectiveness of BMI in representing metabolic health has faced criticism for its inability to distinguish between types of body fat [6, 7]. Perirenal fat (PF), a specific kind of metabolically active visceral adipose tissue [8], has been linked to metabolic dysfunctions and disorders related to obesity [9–12]. In a clinical study involving 40 subjects undergoing percutaneous nephrolithotomy, it was observed that the average PF volume (PFV) was substantially greater in kidneys with stones than in those without [13]. However, it has been reported that the left PFV is greater than the right PFV in both males and females [14]. Therefore, analyzing the perirenal fat without distinguishing between the left and right sides will bring bias to the results. The objective of this research is to delineate the characteristics of PF on both the left and right sides and examine its association with the development of renal calculi. Additionally, evidence is scarce on the association between the relative amount of PF and KS. Consequently, this study also examines the correlation between the ratio of perirenal fat thickness (PFT) to renal parenchymal thickness (RPT) (PFT/RPT) and KS.

Methods

Patients and data collection

This study included individuals who received urological CT scans at the First Affiliated Hospital of Anhui Medical University from December 2022 to May 2023. Participants were stratified into two groups based on CT results: those with KS and a control group devoid of stones. Inclusion criteria for the kidney stone group required a diagnosis of KS via urinary CT scans, an age of 18 years or older, and the absence of any metabolic diseases affecting fat metabolism. Exclusion criteria included any history of cancer, prior kidney stone surgeries, or laparoscopic kidney surgery. Additionally, 61 normal individuals without KS were included. These individuals were also 18 years or older, lacked endocrine disorders affecting fat metabolism, and were not undergoing treatments influencing fat distribution. The collected demographic and clinical data encompassed age, gender, BMI, and history of diabetes mellitus (DM) and hypertension, along with key laboratory findings including creatinine levels, leukocyte count, and estimated glomerular filtration rate (eGFR). Stone data collected included diameter, Hounsfield units (HU), and stone chemical components.

Measurement of PF

All CT-scans were performed on Light Speed VCT 64 (General Electric, Milwaukee, USA) with the patients in a supine position. The images were then transferred to workstations (AW Volume Share 7, GE, USA). Trained radiologists, unaware of the patients' clinical information, measured the scans. PF was distinguished from other tissues using HU density values with a window width ranging from – 195 to -45 HU and centered at -120 HU [14].

The measurement of PFT

PFT was quantified by measuring the maximum distance from the posterior renal surface to the inner abdominal wall at the level of the renal hilum (renal vein) [15], utilizing the workstation's ruler function (Fig. 1A).

The measurement of perirenal fat surface area (PFSA)

PFSA was assessed at the level corresponding to the left renal vein, spanning from the anterior renal fascia to the lateroconal ligament, covering retroperitoneal and posterior PF below the Zuckerkandl fascia (Fig. 1B) [16, 17].

The measurement of PFV

Based on CT images transferred to the workstation, the visible boundaries of the Gerota fascia were measured at three levels: cross-sectional, sagittal, and coronal. To calculate the PFV, structures such as the adrenal, renal, and renal hilum were excluded from the surrounding PF based on the HU values characteristic of fat tissue, as well as 3D rendering of volume measurements [13] (Fig. 1C).

The measurement of RPT

RPT was defined as the length of the shortest diameter line of renal parenchyma parallel to the renal pelvis, extending from the renal capsule to the renal collecting system. This measurement was taken at one level and moved three scanning layers towards both the upper and lower poles to obtain two additional values. The average of these three values was calculated (Fig. 1D) [18].

Statistical analysis

Statistical methodologies included the use of means ± standard deviations (SD) for normally distributed descriptive data, with group comparisons via t-tests. Descriptive variables that exhibited a non-normally distribution was expressed using medians and quartiles (Q1, Q3), and group differences were evaluated through the Wilcoxon test. Frequencies (proportions) were employed for categorical variables, with chi-square tests for group comparisons. Paired samples Wilcoxon tests assessed differences in PF-related metrics between the left and

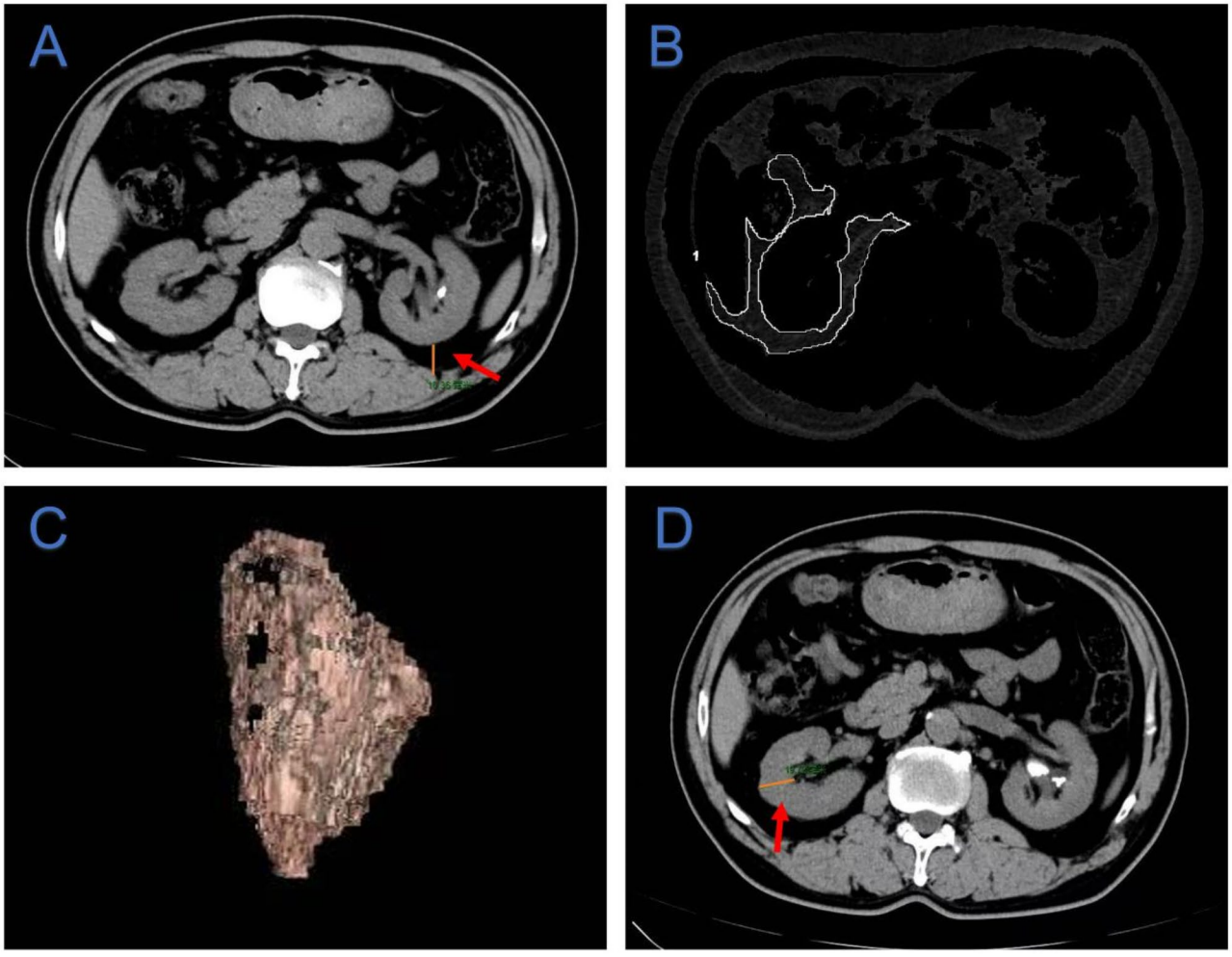

Fig. 1 Assessment of PF-related metrics. (**A**): Measurement of PFT. (**B**): Measurement of PFSA. (**C**): Measurement of PFV. (**D**): Measurement of RPT

right sides within individuals. The association between PF and BMI was investigated using Pearson's correlation coefficient. Clinical predictors of kidney stone presence were evaluated through both univariate and multivariate regression analyses. Statistical analyses were carried out using SPSS version 25.0 software with a significance level of $P < 0.05$ was applied.

Results

161 subjects were recruited, comprising 100 individuals in the kidney stone cohort and 61 in the control group. The research introduced a novel metric akin to the Waist-to-Hip Ratio (WHR): PFT/RPT, as detailed in Table 1 which outlines the clinical characteristics of both cohorts. No notable variances were found in either age or BMI across the groups. It was observed that the kidney stone cohort exhibited significantly higher values of PFT, PFSA, PFT/RPT, and PFV compared to the control group. Furthermore, the study analyzed the disparity in PF between the left and right sides of the normal group, revealing that the left side exceeded the right (Supplementary Fig. 1). Then, the left kidney was divided into left stone-bearing and non-stone-bearing categories, resulting in 72 left stone-bearing kidneys and 89 non-stone-bearing kidneys. A similar classification was applied to the right kidney, yielding 50 right stone-bearing kidneys and 111 stone-free kidneys.

The correlation between PF-related indicators and BMI and the maximum diameter of stones was evaluated and summarized in Tables 2 and 3. The findings showed a weak to extremely weak positive correlation between PFV, PFT, PFSA, PFT/RPT, and BMI. However, no significant correlation was observed between PFV, PFT, PFSA, PFT/RPT and stone burden.

Univariate logistic regression analysis identified gender, hypertension, diabetes, and related PF indicators as risk factors for the left stone-bearing kidney, while for the right stone-bearing kidney, risk factors included gender and hypertension (Supplementary Tables 1 and 2). Due to collinearity between PFT and PFT/RPT, PFT was

Table 1 Demographic and baseline characteristics of the participants in the study

Variable	Kidney stone group ($n=100$)	Normal group ($n=61$)	*P*
Age (years)	54.92 ± 9.02	54.62 ± 6.05	0.803
Gender, men n (%)	70(70.0%)	26(42.6%)	0.001
BMI (kg/m^2)	24.51 ± 3.23	24.33 ± 2.89	0.727
Creatinine (μmol/L)	79.50 (65.00, 92.00)	63.00 (52.50, 78.00)	< 0.001
Leukocytes	6.70 ± 1.62	6.38 ± 1.96	0.262
eGFR	96.50 (80.50, 106.00)	106.00 (98.00, 113.00)	< 0.001
PFT (mm)			
Left	13.18 (8.76, 18.41)	6.89 (4.60, 11.07)	< 0.001
Right	11.30 (7.41, 16.21)	5.42 (3.60, 8.68)	< 0.001
PFSA (mm^2)			
Left	1575.20 (1118.15, 2319.38)	1108.80 (661.15, 1665.30)	< 0.001
Right	1295.30 (846.53, 1943.75)	831.30 (515.20, 1245.60)	< 0.001
PFV (cm^3)			
Left	141.50 (101.25, 212.00)	85.95 (56.27, 146.00)	< 0.001
Right	118.50 (81.87, 167.75)	64.48 (42.24, 123.00)	< 0.001
PFT/RPT			
Left	0.74 (0.47, 1.05)	0.33 (0.22, 0.50)	< 0.001
Right	0.55 (0.34, 0.91)	0.26 (0.15, 0.39)	< 0.001
RPT (mm)			
Left	18.30 ± 3.89	21.12 ± 3.21	< 0.001
Right	20.72 ± 4.55	22.38 ± 4.28	0.023
kidney volume (cm^3)			
Left	192.50 (152.60, 230.93)	161.00 (142.98, 194.00)	0.002
Right	179.35 (155.50, 218.50)	156.00 (141.26, 189.91)	0.002
History of hypertension, yes (%)	32.0%	4.9%	< 0.001
History of diabetes, yes (%)	15.0%	0.0%	0.001

Note: For normally distributed data, they are reported as mean ± SD; for non-normally distributed data, they are reported as median (Q1, Q3); BMI = body mass index; eGFR = estimated glomerular filtration rate; PFT = perirenal fat thickness; PFSA = perirenal fat surface area; PFV = perirenal fat volume; RPT = renal parenchymal thickness

Table 2 The association between perirenal fat related variables and BMI

Correlation	*R* Value	*P* Value
RPFT and BMI	0.265	0.001
RPFSA and BMI	0.344	< 0.001
RPFV and BMI	0.381	< 0.001
RPFT/RRPT and BMI	0.190	0.016
LPFT and BMI	0.242	0.002
LPFSA and BMI	0.197	0.012
LPFV and BMI	0.292	< 0.001
LPFT/LRPT and BMI	0.354	< 0.001

Note: BMI = body mass index; RPFT = right perirenal fat thickness; RPFSA = right perirenal fat surface area; RPFV = right perirenal fat volume; RRPT = right renal parenchymal thickness; LPFT = left perirenal fat thickness; LPFSA = left perirenal fat surface area; LPFV = left perirenal fat volume; LRPT = left renal parenchymal thickness

Table 3 The association between perirenal fat related variables and the maximum diameter of stones

Correlation	*R* Value	*P* Value
PFT and the maximum diameter of stones	0.045	0.694
PFSA and the maximum diameter of stones	0.110	0.337
PFV and the maximum diameter of stones	0.124	0.280
PFT/RPT and the maximum diameter of stones	0.158	0.167

Note: PFT = perirenal fat thickness; PFSA = perirenal fat surface area; PFV = perirenal fat volume; RPT = renal parenchymal thickness

excluded from the multivariate logistic regression analysis (Supplementary Tables 3 and Supplementary Table 4). Multivariate logistic regression analysis revealed PFT/RPT as an independent predictor for KS (Fig. 2). After adjustment for gender, history of hypertension and diabetes, PFSA and PFV, the risk associated with PFT/RPT increased significantly (Left: odds ratio (OR) = 4.042, 95% confidence interval (CI): 2.137–7.645, $P < 0.001$; Right: OR = 5.414, 95% CI: 2.755–10.637, $P < 0.001$).

Receiver operating characteristic (ROC) curves for PFT/RPT were conducted to predict KS. The results demonstrated substantial predictive ability for PFT/RPT. The area under the curves (AUC) for PFT/RPT was 0.817 on the left and 0.840 on the right. The cut-off points were identified as PFT/RPT > 0.573 on the left and PFT/RPT > 0.540 on the right (Supplementary Fig. 2).

Subgroup analysis using ROC curves established gender-specific thresholds for predicting KS. The cut-off points for left PFT/RPT were determined as > 0.582 for males and > 0.323 for females. For the right PFT/RPT, the

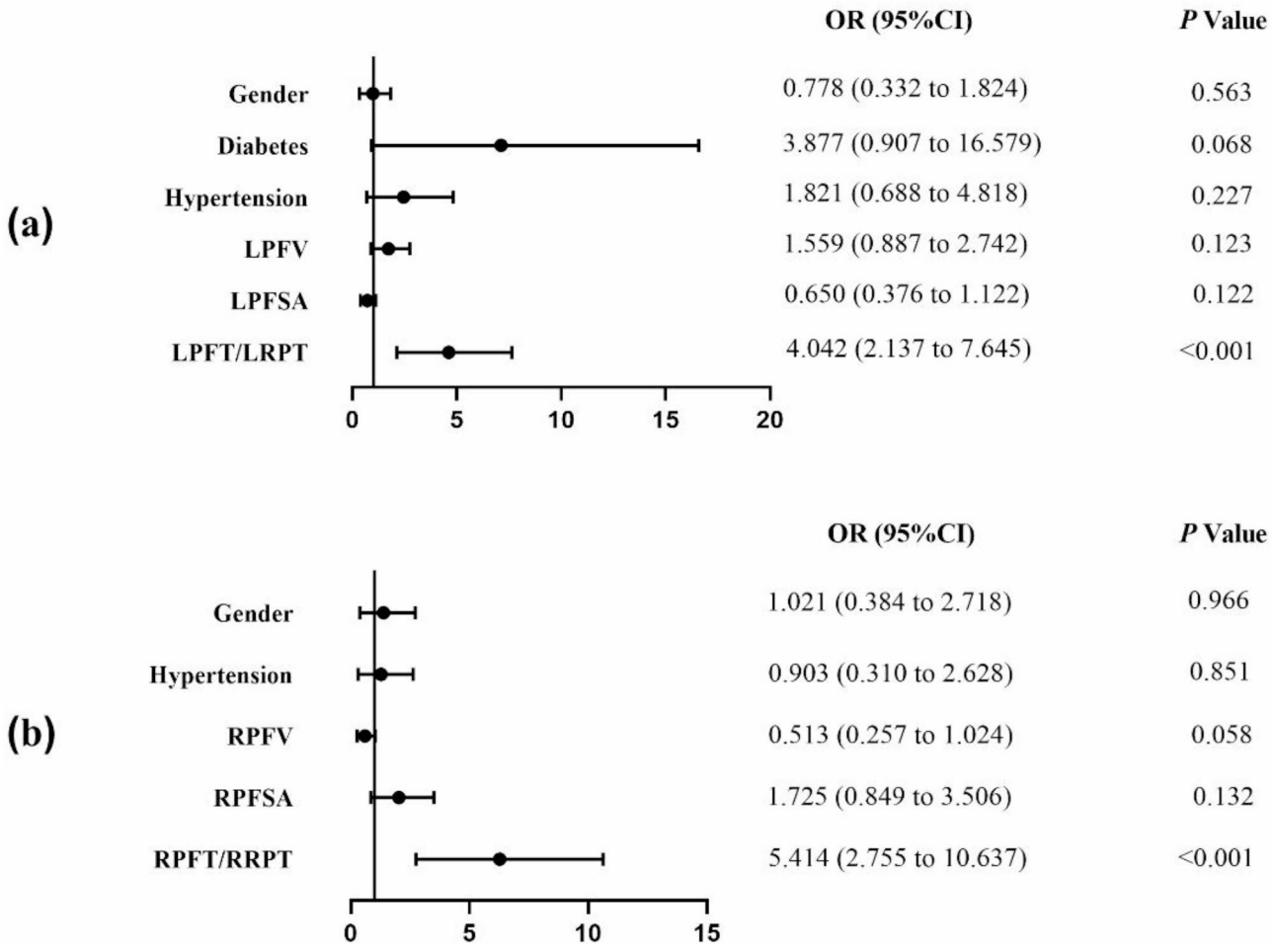

Fig. 2 Multivariate logistic regression analysis of stone bearing kidney. (**a**): Left. (**b**): Right

thresholds were > 0.540 for males and > 0.326 for females (Fig. 3).

A further study on the correlation between the PFT/RPT ratio and kidney stone composition showed that the stone composition in patients with low and high PFT/RPT ratios was not significantly different. (Supplementary Table 5).

Discussion

This study examined whether the PFT/RPT was correlated with KS. After adjusting for confounding factors, it was found that PFT/RPT was significantly correlated with KS.

Contrary to many studies, this research indicated that BMI was not linked to KS. However, a study by Fan et al. [19], involving 10,281 Chinese participants, also reported no difference in BMI between urinary stone patients and those without. The limitations of BMI include its failure to differentiate between subendothelial and visceral fat accumulation. Additionally, the implications of obesity may vary across different ethnic groups for a given BMI [20, 21], such as in some Asian populations who exhibit a lower relative risk.

Regarding PFT, PFSA, and PFV, the PFT/RPT ratio offered a more accurate assessment of PF proportion, correlating a higher ratio with a heightened occurrence of KS. Variability in the prevalence of KS and PF accumulation was apparent between genders; females presented a lower incidence of KS and reduced PF accumulation. Research indicates that females possess a greater ratio of subcutaneous fat compared to males [22], implying that abdominal fat accumulation in males may be more pronounced and potentially exert a greater influence on kidney health, thereby elevating the probability of males developing stones.

Previous studies on the relationship between KS and PF used relatively small sample sizes. Huang et al. [23] measured PFT via CT in 81 patients with unilateral nephrolithiasis and found a significant association between increased PFT and a higher recurrence rate of nephrolithiasis. Additionally, the PFT in kidneys with stones was significantly elevated compared to those without stones, emphasizing the significance of PFT in the pathogenesis

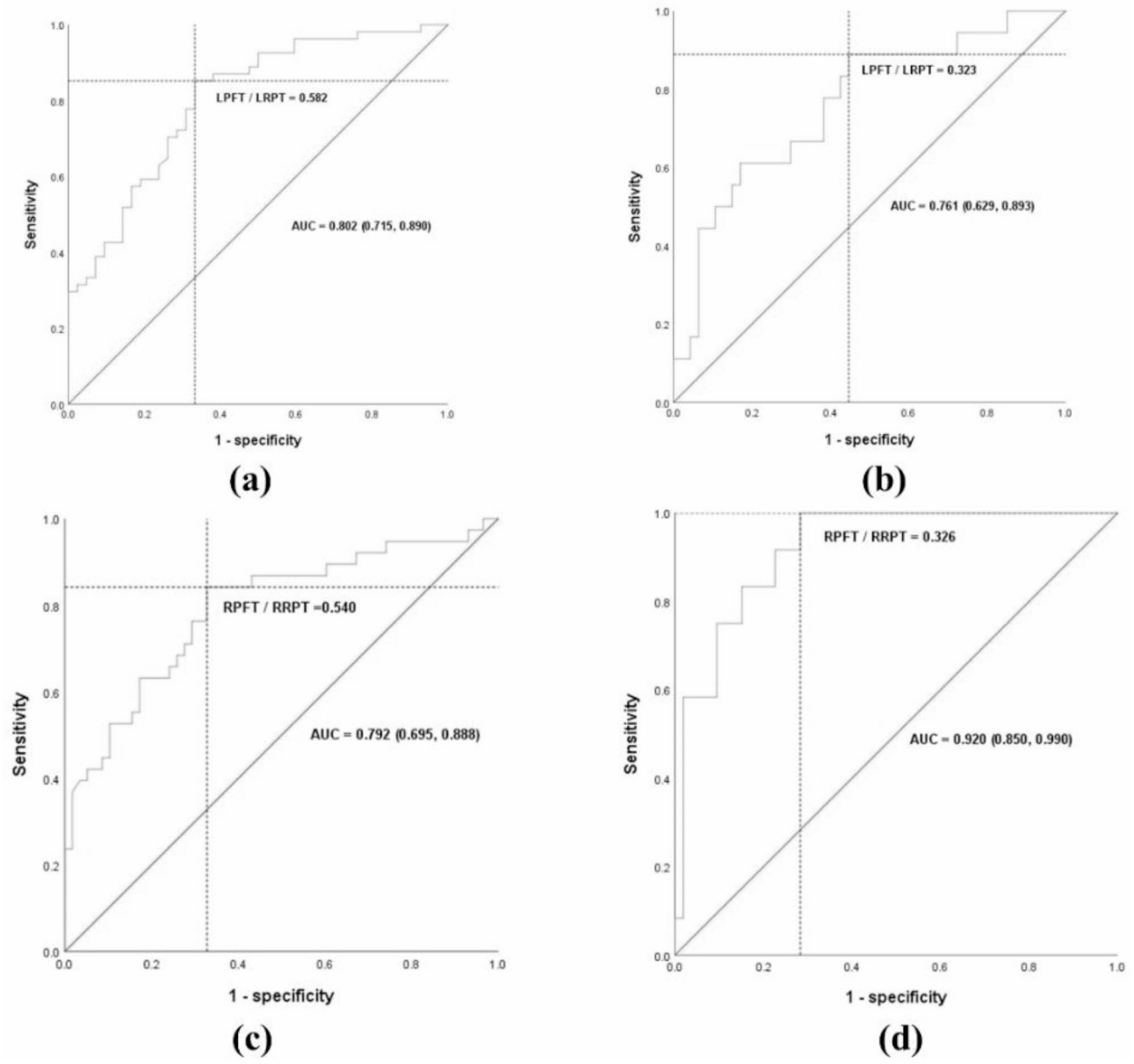

Fig. 3 Receiver operating characteristic (ROC) curve for PFT/RPT predicting kidney stone grouped by gender. (**a**): Left kidney in males. (**b**): Left kidney in females. (**c**): Right kidney in males. (**d**): Right kidney in females

of KS. Complementary findings were reported in another study [13] involving 40 participants where 3D-imaging software was employed to assess PFV, demonstrating that PFV was significantly larger in kidneys with stones than in those without, a result supported by Tastemur et al. [24]. However, the small sample sizes and unidimensional analysis of these studies may not fully capture the complexity of PF distribution, and not distinguishing between left and right side analyses may lead to inaccuracies.

The mechanisms linking increased nephrolithiasis risk to PF are not well understood. PF synthesizes and secretes adipokines and inflammatory factors [8]. Inflammatory mediators such as tumor necrosis factor alpha (TNF-α) [25] and interleukin 6 (IL-6) [26, 27], along with adipokines including adiponectin [28], visfatin [28] and leptin [28], are secreted by PF. These biochemical agents are implicated in modulating lipid and glucose metabolism, insulin sensitivity, and inflammation [29, 30], ultimately escalating the risk of developing KS. A 2016 study [25] found that pigs with thicker PF exhibited increased proinflammatory macrophage infiltration, reactive oxygen species production, and TNF-α expression compared to leaner pigs, suggesting a potential link to urinary stone disease. Li et al. [31] observed that TNF-α was significantly upregulated in mouse renal tubular cells cocultured with adipocytes. Additionally, they noted a marked

increase in calcium oxalate monohydrate crystals in these cells. These findings support the idea that TNF-α from PF may affect renal tubular cells via a paracrine mechanism.

Furthermore, excessive perirenal adipose tissue exerts mechanical pressure on renal blood vessels and renal parenchyma. This pressure can alter renal hemodynamics, such as increasing renal interstitial hydrostatic pressure [32], which may impact kidney filtration and reabsorption processes. Previous research [33] demonstrated that renal cell damage due to renal ischemia could accelerate the calcium oxalate precipitation reaction. Thus, excessive PF might expedite calcium oxalate deposition by compressing renal blood flow.

Strengths and limitations

This study explored the relationship between PFT/RPT and KS, identifying a significant association for the first time. The results provide valuable new insights and evidence that could guide clinical management of KS. Additionally, acknowledging the different distribution patterns of PF in males and females, a subgroup analysis was conducted to examine the connection across both genders.

However, this study is not without limitations. Primarily, it was executed in a single institution with a confined cohort size, potentially introducing bias and undermining the generalizability of the results. Additionally, the limited number of follow-up cases concerning kidney stone recurrence curtailed the capacity for a thorough analysis of the correlation between PFT/RPT and stone recurrence. Moreover, the retrospective design of this study inhibited the exploration of causative mechanisms connecting PF to kidney stone pathogenesis.

Conclusion

In conclusion, this study demonstrated a significant correlation between PFT/RPT and KS. Patients with KS showed greater accumulation of perirenal adipose than healthy individuals. The clinical significance of this study lies in its identification of novel indicators for early risk assessment of KS. These findings enable clinicians to identify high-risk populations and develop personalized prevention and intervention strategies, focusing particularly on reducing PF to lower the risk of KS in these individuals.

Abbreviations

AUC	Area under the curve
BMI	Body mass index
CI	Confidence interval
CT	Computed tomography
DM	Diabetes mellitus
eGFR	Estimated glomerular filtration rate
HU	Hounsfield units
IL-6	Interleukin 6
KS	Kidney stones
OR	Odds ratio
PF	Perirenal fat
PFSA	Perirenal Fat Surface Area
PFT/RPT	The ratio of perirenal fat thickness to renal parenchymal thickness
PFT	Perirenal Fat Thickness
PFV	Perirenal fat volume
ROC	Receiver operating characteristic
RPT	Renal Parenchymal Thickness
SD	Standard deviation
TNF-α	Tumor necrosis factor alpha
WHR	Waist-to-hip Ratio

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12944-025-02497-7 .

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Supplementary Material 6

Supplementary Material 7

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Not applicable.

Author contributions

HZY designed and prepared the manuscript and the study. HDK and LGX were in charge of data collection and analysis. GDF and SHM processed image data. KLL carried out the manuscript review. CY made revisions to the manuscript and HZY offered constructive suggestions. All authors read the final manuscript and gave their approval.

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The procedures carried out in the studies involving human participants complied with the regulations of the Institutional Review Board of the First Affiliated Hospital of Anhui Medical University, where the studies were carried out (IRB approval number PJ 2024-05-94).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Abufaraj M, Xu T, Cao C, Waldhoer T, Seitz C, D'Andrea D, Siyam A, Tarawneh R, Fajkovic H, Schernhammer E, et al. Prevalence and trends in kidney stone

among adults in the USA: analyses of National health and nutrition examination survey 2007–2018 data. Eur Urol Focus. 2021;7:1468–75.
2. Tan S, Yuan D, Su H, Chen W, Zhu S, Yan B, Sun F, Jiang K, Zhu J. Prevalence of urolithiasis in China: a systematic review and meta-analysis. BJU Int. 2024;133:34–43.
3. Xu JZ, Li C, Xia QD, Lu JL, Wan ZC, Hu L, Lv YM, Lei XM, Guan W, Xun Y, Wang SG. Sex disparities and the risk of urolithiasis: a large cross-sectional study. Ann Med. 2022;54:1627–35.
4. Ye Z, Xiao H, Liu G, Qiao Y, Zhao Y, Ji Z, Fan X, Li R, Wang O. Subcutaneous adipose tissue accumulation is an independent risk factor of urinary stone in young people. Front Endocrinol (Lausanne). 2022;13:865930.
5. Mallio CA, Cea L, D'Andrea V, Buoso A, Bernetti C, Beomonte Zobel B, Greco F. Visceral adiposity and its impact on nephrolithiasis: a narrative review. J Clin Med. 2024;13.
6. Dierkes J, Dahl H, Lervaag Welland N, Sandnes K, Sæle K, Sekse I, Marti HP. High rates of central obesity and sarcopenia in CKD irrespective of renal replacement therapy - an observational cross-sectional study. BMC Nephrol. 2018;19:259.
7. Sahi G, Reid J, Moist L, Chiu M, Vinson A, Stranges S, Naylor K, Zhu Y, Clemens KK. Prevalence, characteristics, and outcomes of people with a high body mass index across the kidney disease spectrum: a population-based cohort study. Can J Kidney Health Dis. 2024;11:20543581241293199.
8. Huang N, Mao EW, Hou NN, Liu YP, Han F, Sun XD. Novel insight into perirenal adipose tissue: a neglected adipose depot linking cardiovascular and chronic kidney disease. World J Diabetes. 2020;11:115–25.
9. Chen X, Mao Y, Hu J, Han S, Gong L, Luo T, Yang S, Qing H, Wang Y, Du Z, et al. Perirenal fat thickness is significantly associated with the risk for development of chronic kidney disease in patients with diabetes. Diabetes. 2021;70:2322–32.
10. Roever L, Resende ES, Veloso FC, Diniz AL, Penha-Silva N, Casella-Filho A, Dourado PM, Chagas AC. Perirenal fat and association with metabolic risk factors: the Uberlândia heart study. Med (Baltim). 2015;94:e1105.
11. Ricci MA, Scavizzi M, Ministrini S, De Vuono S, Pucci G, Lupattelli G. Morbid obesity and hypertension: the role of perirenal fat. J Clin Hypertens (Greenwich). 2018;20:1430–7.
12. Fang Y, Xu Y, Yang Y, Liu C, Zhao D, Ke J. The relationship between perirenal fat thickness and reduced glomerular filtration rate in patients with type 2 diabetes. J Diabetes Res. 2020;2020:6076145.
13. Lama DJ, Safiullah S, Yang A, Okhunov Z, Landman J, Clayman RV. Three-dimensional evaluation of perirenal fat volume in patients with nephrolithiasis. Urolithiasis. 2018;46:535–41.
14. Favre G, Grangeon-Chapon C, Raffaelli C, François-Chalmin F, Iannelli A, Esnault V. Perirenal fat thickness measured with computed tomography is a reliable estimate of perirenal fat mass. PLoS ONE. 2017;12:e0175561.
15. Davidiuk AJ, Parker AS, Thomas CS, Leibovich BC, Castle EP, Heckman MG, Custer K, Thiel DD. Mayo adhesive probability score: an accurate image-based scoring system to predict adherent perinephric fat in partial nephrectomy. Eur Urol. 2014;66:1165–71.
16. Chesbrough RM, Burkhard TK, Martinez AJ, Burks DD. Gerota versus Zuckerkandl: the renal fascia revisited. Radiology. 1989;173:845–6.
17. Jung M, Volonté F, Buchs NC, Gayet-Ageron A, Pugin F, Gervaz P, Ris F, Morel P. Perirenal fat surface area as a risk factor for morbidity after elective colorectal surgery. Dis Colon Rectum. 2014;57:201–9.
18. Kaplon DM, Lasser MS, Sigman M, Haleblian GE, Pareek G. Renal parenchyma thickness: a rapid estimation of renal function on computed tomography. Int Braz J Urol. 2009;35:3–8.
19. Fan X, Kalim S, Ye W, Zhao S, Ma J, Nigwekar SU, Chan KE, Cui J, Cai J, Wang L, et al. Urinary stone disease and cardiovascular disease risk in a rural Chinese population. Kidney Int Rep. 2017;2:1042–9.
20. Lear SA, Humphries KH, Kohli S, Birmingham CL. The use of BMI and waist circumference as surrogates of body fat differs by ethnicity. Obes (Silver Spring). 2007;15:2817–24.
21. Wu Y, Li D, Vermund SH. Advantages and limitations of the body mass index (BMI) to assess adult obesity. Int J Environ Res Public Health. 2024;21.
22. Kammerlander AA, Lyass A, Mahoney TF, Massaro JM, Long MT, Vasan RS, Hoffmann U. Sex differences in the associations of visceral adipose tissue and cardiometabolic and cardiovascular disease risk: the Framingham heart study. J Am Heart Assoc. 2021;10:e019968.
23. Huang H, Chen S, Zhang W, Wang T, Bai P, Xing J, Wang H, Chen B. High perirenal fat thickness predicts a greater risk of recurrence in Chinese patients with unilateral nephrolithiasis. Ren Fail. 2023;45:2158870.
24. Tastemur S, Senel S, Olcucuoglu E, Uzun E. Evaluation of the relationship between fat volume and nephrolithiasis. Curr Med Imaging. 2022;18:398–403.
25. Ma S, Zhu XY, Eirin A, Woollard JR, Jordan KL, Tang H, Lerman A, Lerman LO. Perirenal fat promotes renal arterial endothelial dysfunction in obese swine through tumor necrosis factor-α. J Urol. 2016;195:1152–9.
26. Kim OY, Lee SM, Do H, Moon J, Lee KH, Cha YJ, Shin MJ. Influence of quercetin-rich onion peel extracts on adipokine expression in the visceral adipose tissue of rats. Phytother Res. 2012;26:432–7.
27. Liu BX, Sun W, Kong XQ. Perirenal fat: a unique fat pad and potential target for cardiovascular disease. Angiology. 2019;70:584–93.
28. Lemor A, Mielenz M, Altmann M, von Borell E, Sauerwein H. mRNA abundance of adiponectin and its receptors, leptin and visfatin and of G-protein coupled receptor 41 in five different fat depots from sheep. J Anim Physiol Anim Nutr (Berl). 2010;94:e96–101.
29. Lim S, Meigs JB. Links between ectopic fat and vascular disease in humans. Arterioscler Thromb Vasc Biol. 2014;34:1820–6.
30. Yang J, Li CW, Zhang JR, Qiu H, Guo XL, Wang W. Perirenal fat thickness is associated with metabolic dysfunction-associated fatty liver disease in type 2 diabetes mellitus. Diabetes Metab Syndr Obes. 2023;16:1953–65.
31. Zuo L, Tozawa K, Okada A, Yasui T, Taguchi K, Ito Y, Hirose Y, Fujii Y, Niimi K, Hamamoto S, et al. A paracrine mechanism involving renal tubular cells, adipocytes and macrophages promotes kidney stone formation in a simulated metabolic syndrome environment. J Urol. 2014;191:1906–12.
32. Rea DJ, Heimbach JK, Grande JP, Textor SC, Taler SJ, Prieto M, Larson TS, Cosio FG, Stegall MD. Glomerular volume and renal histology in obese and non-obese living kidney donors. Kidney Int. 2006;70:1636–41.
33. Selvam R, Vijaya A. Effect of renal ischaemia reperfusion on calcium oxalate retention. Indian J Med Res. 2000;111:62–8.

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