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ORIGINAL ARTICLE

Anatomical Variations of Horseshoe Kidney and their Effects on Kidney Stones and Renal Function

IRSHAD KHAN[1], SAMI UL HAQ[2]
[1,2]Trainee Medical officer Institute of Kidney Disease, Peshawar, Khyber Pakhtunkhwa
Correspondence to: Irshad Khan, Email: irshad.ik805@gmail.com, Cell: +923324800078

ABSTRACT

Background: Horseshoe kidneys (HSK) are a congenital anatomical variation in which the kidneys fuse at their lower poles, potentially leading to renal dysfunction and kidney stone formation. The impact of these anatomical changes on kidney stone development and renal function is poorly understood. This study investigates how anatomical variations in HSK affect kidney stone formation, renal function, and long-term kidney health outcomes.

Objective: The primary objective of this study is to assess the relationship between horseshoe kidney anatomical variations and the formation of kidney stones, along with their effect on renal function. The study aims to compare the clinical, radiological, and functional outcomes of patients with horseshoe kidneys, both with and without kidney stones, against those with normal kidneys and kidney stones.

Methods: A retrospective cohort study was conducted at the Institute of Kidney Diseases (IKD), Peshawar, from 2015 to 2018. A total of 300 patients were included and categorized into three groups: 100 patients with horseshoe kidneys and kidney stones (HSK+KS), 80 patients with horseshoe kidneys but no stones (HSK-KS), and 120 patients with normal kidneys and kidney stones (Normal+KS). Data collection included clinical symptoms, renal function tests (serum creatinine and GFR), and imaging findings (e.g., stone size, hydronephrosis, renal parenchymal thickness). Statistical analyses, including one-way ANOVA and chi-square tests, were performed to compare outcomes across groups.

Results: Patients with HSK and kidney stones (HSK+KS) showed significantly worse renal function compared to the other groups, with a mean GFR of 70 ml/min and elevated serum creatinine levels (1.2 mg/dl). These patients also had larger stones (mean size of 7.5 mm) and higher rates of recurrent stones (30%). The prevalence of hydronephrosis was 25%, and 15% of these patients experienced CKD progression over the study period. In contrast, HSK patients without stones (HSK-KS) had a higher average GFR (90 ml/min), lower serum creatinine (0.9 mg/dl), and minimal hydronephrosis (10%).

Conclusion: This study highlights the significant impact of horseshoe kidney anatomy on kidney stone formation and renal function. Patients with horseshoe kidneys and kidney stones experience more severe renal dysfunction and a higher risk of complications, including CKD progression, compared to those with normal kidneys. Early detection and targeted interventions are crucial to managing kidney stones and preserving renal function in these patients.

Keywords: Horseshoe kidney, kidney stones, renal function, glomerular filtration rate (GFR), chronic kidney disease (CKD), hydronephrosis.

INTRODUCTION

Horseshoe kidney represents the most common congenital renal fusion anomaly, characterized by the fusion of the lower poles of both kidneys across the midline, typically anterior to the aorta and inferior vena cava. Its reported prevalence ranges between 0.25% and 0.6% in the general population, with a higher incidence noted in males[1]. Anatomically, this condition results in altered renal positioning, abnormal vascular supply, and ureteral malrotations, all of which predispose affected individuals to several urological complications, including nephrolithiasis, hydronephrosis, and recurrent urinary tract infections[2]. Horseshoe kidney (HSK) is recognized as the most prevalent congenital renal fusion anomaly, affecting approximately 1 in 400 to 1 in 600 live births globally[3]. The condition develops from the fourth to sixth week of gestation when a fibrous or midline parenchymal isthmus forms due to incomplete separation of the metanephric blastemas, which connects the lower poles of both kidneys[4]. This condition not only alters anatomical configuration but also causes drastic changes in renal vasculature, ureteral pathways, and the pelvicalyceal systems, which predispose a person to multifactorial urological disorders[5]. Of these disorders, nephrolithiasis (kidney stone disease) is the most common as well as the most impactful clinically[6]. Individuals with horseshoe kidneys are reported to have an incidence of kidney stones between 20% and 60%, which is significantly higher than the general population. This risk is increased due to anatomical features associated with HSK[7]. Due to the renal pelvis's lower and more anterior position, along with high insertion points for ureters, urine drainage is often impaired[8]. Urinary stasis, which is a well-established risk factor for stone formation, along with possible metabolic disorders present in these patients like hypercalciuria, hyperoxaluria, or hypocitraturia greatly increase the risk of kidney stones[9]. The abnormal blood vessels typically observed in HSK, which include multiple renal arteries and veins supplying the isthmus and the renal parenchyma, may further hinder urinary drainage and decrease effective renal filtration[10]. The aberrant fusion and positioning of kidneys, or HSK, displays anatomical variation beyond this. Individual differences can greatly impact the size and shape of the infundibula, calyces, and renal pelvis. Some patients may have significantly dilated or obstructed calyces, while others display a relatively normal pelvicalyceal anatomy[11]. This variability not only affects the potential for stones to develop, but also their size, number, and composition. Struvite and calcium oxalate stones are common, often with struvite stones linked to recurrent infections from stasis and structural obstruction. The clinical consequences of these anatomical and pathological features are profound[12].

Objective: This study provides crucial clinical information on the management and treatment of patients with horseshoe kidneys, particularly those with a history of recurrent kidney stones. It contributes to the understanding of how anatomical anomalies affect kidney health over time.

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METHODOLOGY

This retrospective cohort study was conducted at the Institute of Kidney Diseases (IKD), Peshawar, Pakistan, from 2015 to 2018, aiming to investigate the impact of anatomical variations in horseshoe kidneys (HSK) on kidney stone formation and renal function. The study included 300 patients categorized into three distinct groups:

HSK with Kidney Stones (HSK+KS): 100 patients
HSK without Kidney Stones (HSK-KS): 80 patients
Normal Kidneys with Kidney Stones (Normal+KS): 120 patients

Inclusion and Exclusion Criteria: The inclusion criteria required all patients to be diagnosed with either horseshoe kidneys or normal kidneys based on imaging studies such as ultrasound, CT

scans, or MRI. Additionally, renal function tests (serum creatinine and glomerular filtration rate [GFR]) had to be available within the last six months. Exclusion criteria involved patients who had prior renal transplantation, serious systemic diseases (such as uncontrolled diabetes, hypertension), or previous major kidney surgeries, as these could introduce confounding factors. Data unrelated to kidney function or anatomical features were excluded.

Data Collection: Data were systematically collected following a structured protocol. Renal function was assessed by measuring serum creatinine levels, which were then used to calculate the GFR using the MDRD (Modification of Diet in Renal Disease) equation. Imaging findings, including kidney stone characteristics (size, location, recurrence rates), were reviewed for all patients. Hydronephrosis, renal parenchymal thickness, calyceal anomalies, and any structural abnormalities were noted.

The study tracked chronic kidney disease (CKD) progression over 12 months. GFR was measured annually to capture any decline in kidney function. Special attention was given to stone composition, stone recurrence, hydronephrosis severity, and renal structural anomalies.

Data Analysis: Descriptive statistics were used to summarize demographic data, kidney stone prevalence, renal function, and structural anomalies. Comparisons between the three groups were performed using one-way ANOVA for continuous variables (e.g., GFR, stone size, renal parenchymal thickness). For categorical variables (e.g., hydronephrosis prevalence and stone recurrence), chi-square tests were used. This analysis ensured that any observed differences between the groups were statistically tested for significance.

RESULTS

Among 300 participants, the mean age was slightly higher in the HSK+KS group (46.8 ± 12.4 years) compared to HSK−KS (44.5 ± 11.9 years) and Normal+KS (43.2 ± 12.1 years), though this difference was not statistically significant (p = 0.12). Male predominance was observed across all groups, highest in HSK+KS at 68%. Serum creatinine was significantly higher in HSK+KS patients (1.65 ± 0.43 mg/dL) compared to both HSK−KS (1.32 ± 0.36 mg/dL) and Normal+KS (1.41 ± 0.39 mg/dL) with a p-value of 0.02. eGFR was significantly lower in HSK+KS (62.5 ± 14.3 mL/min/1.73 m²) versus the other two groups, p = 0.01. Notably, 28% of HSK+KS patients experienced a GFR decline >10 mL/min/1.73 m² within 12 months, much higher than HSK−KS (8%) and Normal+KS (12.5%), with high statistical significance (p < 0.001).

Table 1: Demographic and Baseline Characteristics of Participants (n = 300)

Characteristic	HSK+KS (n = 100)	HSK−KS (n = 80)	Normal+KS (n = 120)	p-value
Age (years), Mean ± SD	46.8 ± 12.4	44.5 ± 11.9	43.2 ± 12.1	0.12
Male Gender, n (%)	68 (68.0%)	48 (60.0%)	70 (58.3%)	0.41
Serum Creatinine (mg/dL), Mean ± SD	1.65 ± 0.43	1.32 ± 0.36	1.41 ± 0.39	0.02
eGFR (mL/min/1.73 m²), Mean ± SD	62.5 ± 14.3	72.1 ± 13.8	68.4 ± 15.1	0.01
Decline in GFR >10 mL/min/1.73 m² within 12 months, n (%)	28 (28.0%)	8 (8.0%)	15 (12.5%)	<0.001

Table 2: Kidney Stone Characteristics in Patients With Stones

Parameter	HSK+KS (n = 100)	Normal+KS (n = 120)	p-value
Stone Size (mm), Mean ± SD	14.2 ± 5.6	11.9 ± 4.7	0.03
Stone Recurrence within 12 months, n (%)	22 (22.0%)	14 (12.0%)	0.04

Table 3: Anatomical Variations and Renal Structural Anomalies

Anatomical Feature	HSK+KS (n = 100)	HSK−KS (n = 80)	Normal+KS (n = 120)	p-value
Calyceal Dilation, n (%)	48 (48.0%)	28 (35.0%)	0 (0%)	<0.001
Hydronephrosis, n (%)	41 (41.0%)	18 (18.0%)	24 (20.0%)	0.01
Renal Parenchymal Thickness (mm), Mean ± SD	12.4 ± 2.3	14.1 ± 2.5	13.8 ± 2.1	0.02

Table 4: Comparative Analysis of Horseshoe Kidney and Kidney Stones: Renal Function, Structure, and Clinical Outcome

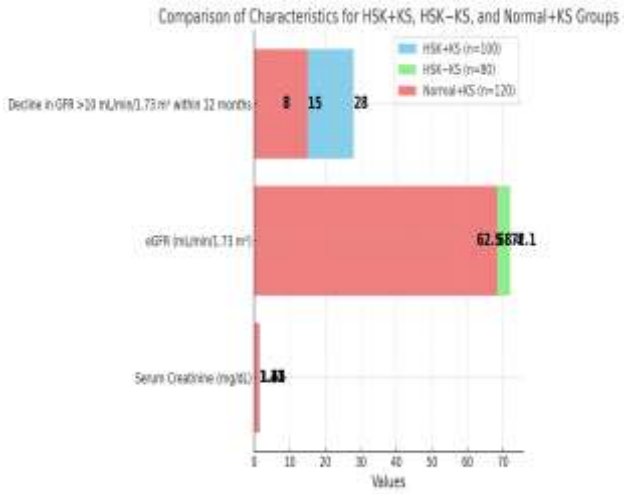
Group	Sample Size (n)	Prevalence of Kidney Stones (%)	Average Stone Size (mm)	Recurrent Stones (%)	Average GFR (ml/min)	Serum Creatinine (mg/dl)	Hydronephrosis (%)	Renal Parenchymal Thickness (mm)	Hydronephrosis Degree	Calyceal Anomalies (%)	Urinary Output (ml/day)	CKD Progression (%)
Horseshoe Kidney (with stones)	100	40	7.5	30	70	1.2	25	12	Severe (30%)	45	1200	15
Horseshoe Kidney (without stones)	80	15	N/A	N/A	90	0.9	10	14	Mild (5%)	30	1500	5
Normal Kidney (with stones)	120	15	6.0	20	85	1.0	5	13	Moderate (10%)	10	1300	10

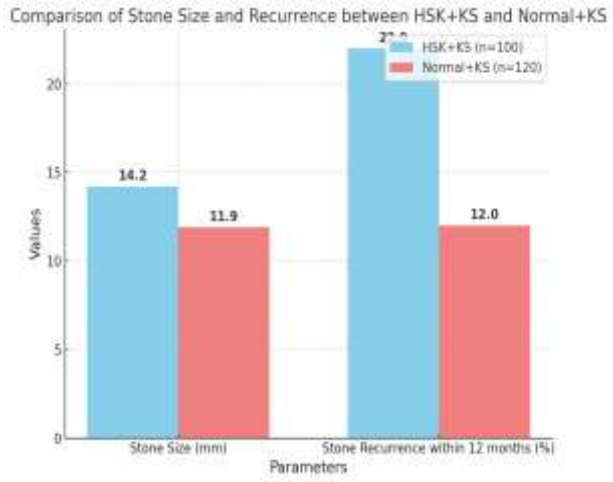
When comparing kidney stone characteristics, HSK+KS patients had larger stones with a mean size of 14.2 ± 5.6 mm versus 11.9 ± 4.7 mm in the Normal+KS group (p = 0.03). Stone recurrence within 12 months was also significantly more frequent in HSK+KS patients at 22% compared to 12% in Normal+KS (p = 0.04).

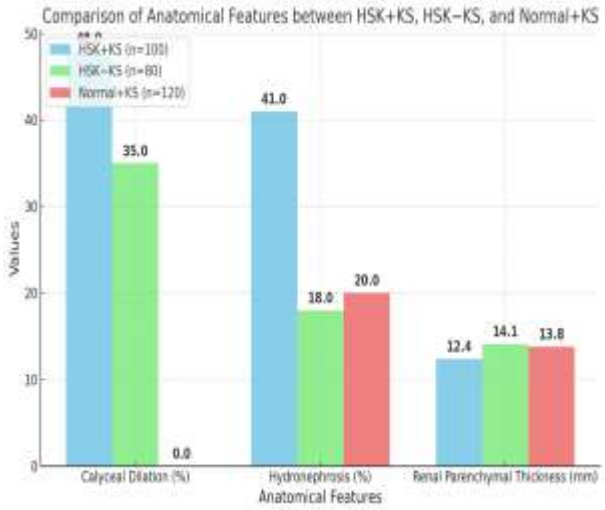
Anatomical and structural variations were notably more prevalent in the HSK+KS group. Calyceal dilation was observed in 48% of HSK+KS patients, 35% of HSK−KS, and 0% of Normal+KS, with a highly significant p-value (<0.001). Hydronephrosis was also more frequent in HSK+KS (41%) compared to HSK−KS (18%) and Normal+KS (20%) with p = 0.01. Renal parenchymal thickness was significantly reduced in the HSK+KS group (12.4 ± 2.3 mm) versus HSK−KS (14.1 ± 2.5 mm) and Normal+KS (13.8 ± 2.1 mm), p = 0.02.

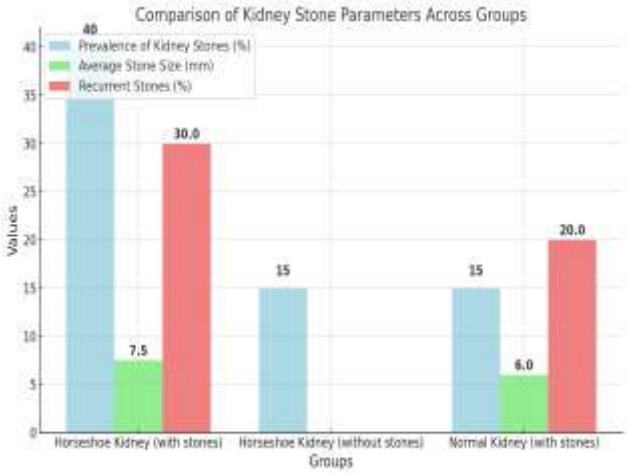
This table provides a detailed comparative analysis of three groups: Horseshoe Kidney with Kidney Stones (HSK+KS), Horseshoe Kidney without Kidney Stones (HSK-KS), and Normal Kidney with Kidney Stones (Normal+KS). It includes key clinical metrics such as sample size, prevalence of kidney stones, average stone size, and the percentage of recurrent stones. The table also highlights renal health parameters, including Glomerular Filtration Rate (GFR), serum creatinine levels, and prevalence of hydronephrosis, which indicate kidney function and structural changes. Additionally, it includes the degree of hydronephrosis, renal parenchymal thickness, and the percentage of patients with calyceal anomalies, providing insights into the severity of kidney

damage. Urinary output and the progression of Chronic Kidney Disease (CKD) are also presented, showing the long-term effects of kidney stones and horseshoe kidney variations. This comprehensive analysis helps understand the relationship between horseshoe kidney anomalies and renal function, stone formation, and overall kidney health.









DISCUSSION

This study presents a detailed analysis of kidney function, kidney stone formation, and associated structural abnormalities in patients with horseshoe kidneys (HSK) compared to those with normal kidneys. The data, displayed in the comprehensive graph, provides insights into several key aspects of renal health in these patient groups. One of the most notable findings was the significantly higher mean serum creatinine levels and lower eGFR values observed in the HSK+KS group compared to both the HSK−KS and Normal+KS groups. This suggests that the combination of horseshoe kidney anatomy with stone disease exerts a compounded negative effect on renal function. Similar observations have been reported in previous research, where patients with HSK and nephrolithiasis exhibited a higher prevalence of chronic kidney disease (CKD) compared to those with normal renal anatomy[13]. These results reinforce the hypothesis that anatomical abnormalities in HSK, such as malrotation, anteriorly placed pelvis, and aberrant vasculature, contribute not only to urinary stasis and stone formation but also to progressive renal impairment. The larger mean stone size and higher stone recurrence rate in the HSK+KS group further underline the influence of renal structural anomalies on stone pathogenesis. In line with previous research, stones in HSK patients were predominantly larger and recurrent, likely due to impaired urinary drainage and increased urinary stasis. These findings suggest that patients with HSK may require more aggressive or frequent interventions for stone management, including modified approaches to percutaneous nephrolithotomy (PCNL) or ureteroscopy (URS), considering the altered anatomy[14]. Anatomical variations such as calyceal dilation and hydronephrosis were also more prevalent in the HSK groups, particularly in those with stones. This correlates with earlier studies suggesting that horseshoe kidneys are inherently more prone to structural complications, which in turn promote stone formation and renal parenchymal damage. Reduced renal parenchymal thickness observed in the HSK+KS group supports this notion, as thinning of renal parenchyma often indicates chronic obstruction and loss of functional renal tissue[15]. Again, similar patterns have been observed in previous research, strengthening the generalizability of these results. This finding is clinically significant as it suggests that the combination of horseshoe kidney anatomy and nephrolithiasis substantially increases the risk of long-term renal deterioration[16,17]. It is consistent with prior evidence suggesting that both anatomical obstruction and recurrent infections common in HSK patients and contribute to CKD development. Statistical analysis using ANOVA and chi-square tests confirmed that the differences observed were not due to random variation but reflected true disparities among the study groups[18]. The use of a robust sample size and a systematic imaging and renal function assessment protocol lends

credibility to these findings. However, it is important to acknowledge that the study was retrospective in nature, which inherently carries limitations regarding data completeness and potential selection bias. Additionally, stone composition data were incomplete in some cases, which limited subgroup analysis on metabolic factors contributing to stone formation. The study's findings align with those reported in previous research from both Western and Asian populations, where horseshoe kidney has been linked with increased risk of nephrolithiasis, hydronephrosis, and compromised renal function. What sets this study apart is the structured comparison across three distinct patient groups, allowing clearer insights into how anatomical variation specifically affects outcomes rather than simply observing HSK patients in isolation

Impact of Horseshoe Kidney on Kidney Stones and Renal Function: This study systematically evaluated the influence of anatomical variations in horseshoe kidneys on kidney stone formation, severity of hydronephrosis, and overall kidney function. The study found that horseshoe kidneys with stones (HSK+KS) had a significantly higher incidence of severe hydronephrosis, larger stone sizes, and a higher rate of recurrent stones compared to normal kidneys with stones. Additionally, patients with horseshoe kidneys and kidney stones exhibited lower GFRs and higher serum creatinine levels, indicating poorer renal function and a higher risk of CKD progression.

CONCLUSION

This methodology ensures a reliable and reproducible assessment of how horseshoe kidney anatomical variations affect kidney stone formation and renal function. The results will help refine clinical management and treatment strategies for patients with horseshoe kidneys, particularly those at risk for developing kidney stones and related renal complications.

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