CASE REPORT

Surgical Anatomy and Vascular Configuration of Horseshoe Kidney: Insights from a Surgically Managed Case

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Abstract

Horseshoe kidney is the most common renal fusion anomaly, arising from abnormal fusion of the metanephric blastema during early embryogenesis. Arrested ascent and incomplete rotation result in a low-lying kidney connected by an isthmus and characterised by highly variable vascular anatomy. These structural variations have important surgical implications.

A 54-year-old man underwent imaging evaluation, which revealed a horseshoe kidney with a parenchymatous isthmus and bilateral malrotation. Contrast-enhanced computed tomography demonstrated a renal mass within the right moiety associated with tumour thrombus extending into the inferior vena cava. Vascular mapping showed three renal arteries supplying each moiety, including a lower polar artery to the left side arising from the right common iliac artery.

The anomaly demonstrated classical lower pole fusion, anteriorly oriented renal pelvises and complex arterial supply with cross-midline contribution. Such vascular heterogeneity and altered anatomical relationships increase the complexity of surgical access, vascular control and resection. Detailed preoperative imaging is essential to define arterial and venous variations and to reduce intraoperative risk. Horseshoe kidney is a surgically significant developmental anomaly. Comprehensive understanding of its embryological basis, morphology and vascular patterns is fundamental to safe operative planning.

Keywords: horseshoe kidney; renal tumour; nephrectomy

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Introduction

Horseshoe kidney (HSK) is the most frequent renal fusion anomaly, occurring in approximately 1 in 400–600 individuals and demonstrating male predominance (1, 2). It is characterised most commonly by fusion of the lower poles in most cases, forming a midline isthmus that connects both renal moieties. The anomaly is best understood not simply as a fusion defect, but as a developmental disorder involving abnormal renal fusion, arrested ascent, incomplete rotation and altered vascular remodelling (2, 3).

Normal renal development involves ascent from the pelvic region to the upper lumbar level, accompanied by medial rotation of the renal hilum. In HSK, ascent is commonly arrested at the level of the inferior mesenteric artery, resulting in a lower-than-normal renal position and incomplete rotation with an anteriorly directed renal hilum (2, 3). The isthmus may consist of functioning renal parenchyma or fibrous tissue, and its relationship to the great vessels is particularly important during retroperitoneal surgery (1).

One of the most clinically significant features of HSK is its vascular variability. Multiple renal arteries frequently arise from the abdominal aorta or the iliac vessels, reflecting the persistence of embryonic arterial channels (4–7). These arterial variations, combined with altered ureteric course, atypical hilar orientation and possible venous anomalies, create considerable challenges during surgery (8–10).

Although often asymptomatic, HSK may be associated with ureteropelvic junction obstruction, urolithiasis, infection and, less commonly, renal malignancy (11–13). When renal cell carcinoma occurs in HSK, operative management requires meticulous anatomical assessment because surgical access, vascular control and preservation of functional renal tissue may be influenced by aberrant vessels and fusion morphology (14, 15). This report describes a surgically managed renal cell carcinoma in HSK and discusses its developmental anatomy, morphological type, vascular configuration and surgical implications.

Case Presentation

A 54-year-old man underwent abdominal imaging evaluation for the investigation of haematuria. Ultrasonography demonstrated elongated, mal-rotated kidneys with medial deviation and fusion of the lower poles via a parenchymatous bridge.

Contrast-enhanced computed tomography confirmed a horseshoe kidney located in a low lumbar position. The renal hilar regions were anteriorly oriented, consistent with incomplete medial rotation. The isthmus consisted of functioning renal parenchyma situated anterior to the abdominal aorta and inferior vena cava, below the level of the inferior mesenteric artery.

A large enhancing mass was identified within the right renal moiety (Figure 1). The tumour thrombus extended along the right renal vein into the inferior vena cava up to the level of the hepatic venous openings.

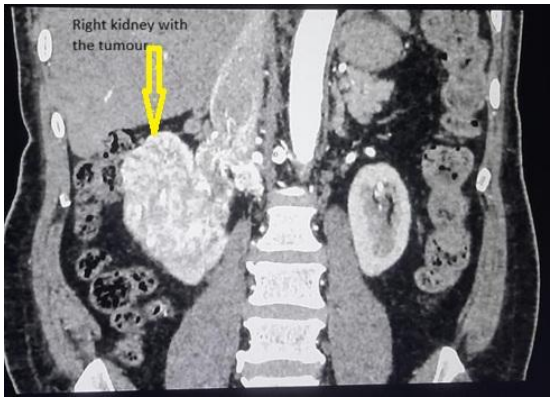


Figure 1: CT image of Right Renal tumour in a horseshoe kidney

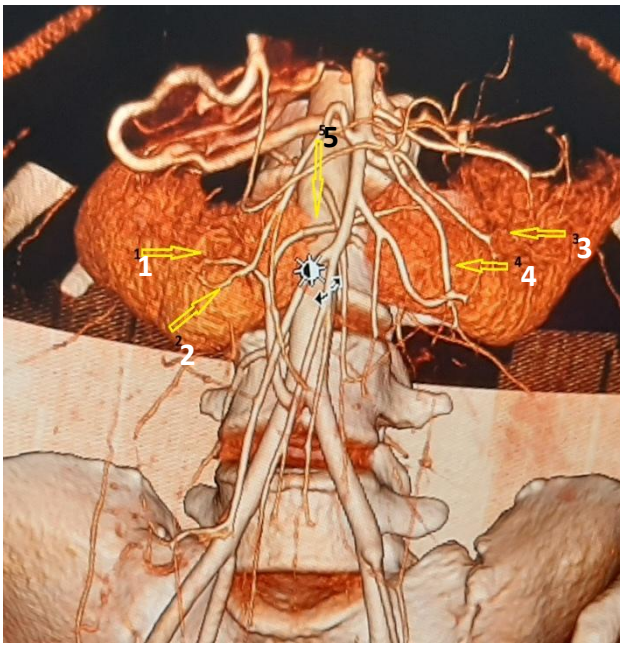


Figure 2: CT angiographic reconstruction showing the arterial configuration of the horseshoe kidney. 1-first right renal moiety artery; 2-second right renal moiety artery; 3-first left renal moiety artery; 4-second left renal moiety artery; and 5-lower polar/isthmic artery arising from the right common iliac artery and dividing near the isthmus

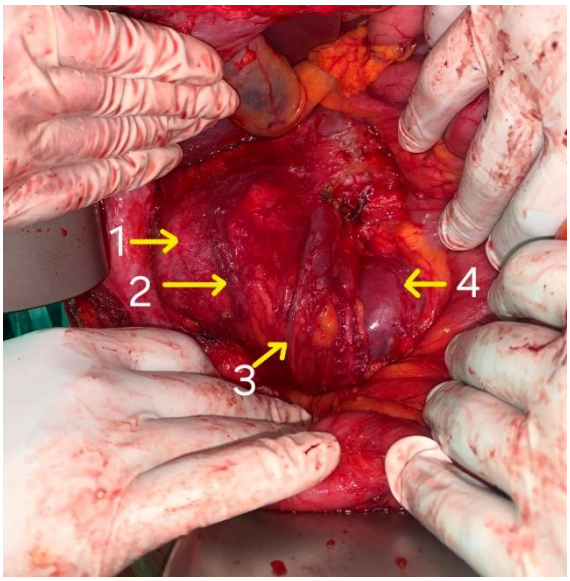


Figure 3: Intra operative finding of the HSK. 1-right moiety; 2-artery to right moiety; 3-isthmus and isthmic artery and 4-left moiety

Discussion

Embryological development

During embryogenesis, the permanent kidneys arise from the metanephros through interactions between the ureteric bud and the metanephric blastema, which drive nephron and collecting system formation. The kidneys initially develop in the pelvis and ascend to the lumbar region between the sixth and ninth weeks of gestation while undergoing medial rotation. During ascent, they establish successive arterial supplies from the abdominal aorta, with inferior vessels normally regressing. Disruption of ascent, rotation or vascular regression results in congenital renal anomalies such as a horseshoe kidney and aberrant renal vasculature (2, 3).

HSK develops between the fourth and sixth weeks of gestation when the metanephric blastema fuses prior to renal ascent. The mechanical fusion theory proposes close apposition of the developing kidneys in the pelvis before migration. Alternative explanations include abnormal nephrogenic cell migration or teratogenic influences during early organogenesis (2, 3).

Ascent of the fused kidneys is typically arrested at the level of the inferior mesenteric artery, resulting in a low lumbar vertebral position. Incomplete medial rotation accounts for the anterior orientation of the renal pelvis and altered hilar configuration. The isthmus most commonly consists of functioning renal parenchyma and is commonly located anterior to the great vessels. This anatomical relationship has major implications during retroperitoneal surgeries (1, 2).

Types of horseshoe kidney

HSK demonstrates morphological variation that can be broadly classified into several types

(1, 2, 12). Most commonly, the fusion occurs at the lower poles (More than 90.0%). In others, the fusion occurs at the upper poles (inverted horseshoe) (11).

Depending on the position of the isthmus relative to the vertebral column, the HSK is classified as symmetric or asymmetric. Left-sided dominant HSK are commoner (in 70.0%) (2). However, the above-described HSK is right-dominant. Detailed morphological assessment is important because the position and tissue composition of the isthmus influence surgical exposure, vascular control and the risk of bleeding or urinary leakage during isthmus mobilisation or division (1, 11).

Vascular anatomy

Vascular heterogeneity is the most surgically relevant feature of HSK (1, 7). The main renal arteries supplying HSK typically originate at lower vertebral levels than those of normally positioned kidneys (5). Each moiety of the HSK is supplied by a large number of arteries than the kidneys; with normal anatomy and position, one artery to each moiety is only seen in 30.0% of cases (5). In a study of 83 individuals with HSK, it was found that the number of arteries supplying each moiety was twice that in normal kidneys (5). Accessory arteries frequently arise from the abdominal aorta, common iliac arteries, internal iliac arteries, external iliac arteries, median sacral artery or other adjacent major vessels, as in the case described above (5–7).

Persistence of embryonic vascular channels explains the multiplicity and variable origin of renal arteries (3, 4). CT-based studies have shown that the number and level of origin of renal arteries in HSK differ substantially from those in normally positioned kidneys, reinforcing the need for individualised preoperative vascular assessment (5, 6). In the present case, the whole horseshoe kidney was supplied by five parent arteries, including two aortic arteries to each moiety and a separate lower polar/isthmic artery from the right common iliac artery. In some cases, the arterial branch to the isthmus may supply the entire kidney, therefore it is essential to delineate the arterial anatomy before any interventions (10). The isthmus receives its blood supply from main renal artery, the common iliac artery, a separate branch from the aorta or even from the inferior mesenteric artery. The isthmus may receive separate arterial branches, as in the present case, where an additional artery arising from the right common iliac artery supplied the isthmus and lower poles (Figure 2). Such a vessel may be mistaken for a minor retroperitoneal branch unless specifically identified on CT angiography. Functionally, each renal moiety received two direct aortic arteries plus an additional lower polar contribution from the iliac artery, demonstrating the importance of mapping both parent vessels and segmental branches before operative intervention (6, 7).

Venous anatomy is also atypical in a high number of cases (23%), increasing the complexity of hilar dissection and vascular control. Major venous anomalies, including abnormalities of the inferior vena cava such as duplication of IVC or left sided-IVC, have been reported in association with HSK and should be assessed preoperatively, particularly when tumour thrombus or major venous mobilisation is anticipated (8).

Surgical and clinical implications

Ultrasonography may suggest the diagnosis of HSK by demonstrating medial deviation and fusion of the lower poles across the midline. However, while ultrasound is useful for morphological recognition, it has limited ability to evaluate complex arterial and venous

anatomy. Cross-sectional imaging provides superior anatomical definition, particularly for evaluating the isthmus, associated complications and vascular configuration (11, 12).

Contrast-enhanced CT and CT angiography are central to operative planning in HSK. They define the number, calibre, origin and course of renal arteries; the relationship of the isthmus to the aorta and inferior vena cava; venous drainage; and the spatial relationship of renal pathology to adjacent structures (5–7). Recent reports also highlight the value of three-dimensional image reconstruction for understanding the relationship between renal moieties, collecting system and aberrant vessels when minimally invasive or reconstructive surgery is planned (16).

The low renal position and anteriorly directed pelvis alter conventional approaches to the renal hilum. Aberrant arteries must be individually identified and preserved to prevent haemorrhage, segmental ischaemia or loss of perfusion to the isthmus and contralateral moiety (6,7). Robotic-assisted partial nephrectomy in HSK has been described, but such procedures remain technically demanding because of reduced renal mobility, variable hilar orientation and abnormal vascular supply (15).

In the present case, tumour thrombus extending into the inferior vena cava required careful consideration of venous anatomy and vascular control. The isthmus and aberrant arterial branches lay in close relationship to the great vessels, creating potential difficulty during IVC mobilisation. Aortic and para-aortic procedures also pose particular hazards because aberrant renal vessels may cross the operative field and may be mistaken for small retroperitoneal vessels or lymphatic structures (9). In patients with abdominal aortic aneurysm and HSK, preservation of accessory renal arteries is important to minimise renal infarction and isthmic ischaemia(10). Therefore, preoperative CT angiography is indispensable before renal, aortic or retroperitoneal surgery in patients with HSK.

Complications of horseshoe kidney

HSK is associated with an increased risk of urinary stasis due to malrotation, anteriorly oriented renal pelvis and altered ureteric course. These changes predispose to ureteropelvic junction obstruction, hydronephrosis, recurrent urinary tract infection and renal calculi (1, 11, 12).

Renal malignancy may also occur in HSK, although renal cell carcinoma does not differ histologically from tumours arising in normally positioned kidneys. Its surgical management, however, is strongly influenced by aberrant vascular anatomy, altered fusion morphology and the relationship of the tumour to the isthmus and great vessels (13, 14). In the present case, renal cell carcinoma arising from the right moiety with tumour thrombus extending into the inferior vena cava represented the clinically significant complication requiring surgical management.
Recent reports continue to emphasise that malignancy in HSK requires detailed preoperative anatomical assessment, because vascular multiplicity, isthmic anatomy and altered orientation of the renal moieties can significantly affect surgical access, resection strategy and vascular control (13, 15).

Conclusion

HSK is a complex developmental anomaly characterised by lower-pole fusion, incomplete rotation and marked vascular heterogeneity. Its morphological subtypes demonstrate vascular, ureteric and positional variations that directly

influence surgical strategy. In the present case, a right renal moiety tumour with inferior vena cava tumour thrombus occurred in the setting of complex cross-midline arterial supply, emphasising the need for detailed preoperative imaging. Recognition of these anatomical variations through CT angiography and understanding of the embryological basis of HSK are essential for safe operative management.

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