Evaluation of Renal Artery Anomalies Associated with Horseshoe Kidney Using CT Angiography

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Purpose: To evaluate the incidence of supernumerary renal arteries in horseshoe kidney (HSK) patients, focusing on number and diameters using computed tomographic angiography (CTA).
Material and methods: Thirty-nine patients with HSK and 103 patients with normal kidney (NK) underwent 64 or 128 multidetector CT. Based on 2-dimensional CT, including multiplanar reconstruction, maximum intensity projection, and volume-rendered images with a 0.5-mm reconstruction interval on CTA, we assessed the incidence of supernumerary renal arteries, and large (> 3 mm in diameter) supernumerary renal arteries, and compared the results between the HSK and NK patients using a chi-square test.
Result: The mean number of renal arteries was 3.87 in HSK patients and 2.41 in the NK patients. The incidence rates of supernumerary arteries and supernumerary arteries greater than 3 mm were 92.3 %, 69.2 % in HSK patients and 33%, 8.7% in NK patients. Supernumerary and large supernumerary renal arteries had significantly higher incidence rates in the HSK patients than in the NK patients on CTA (p = 0.003, < 0.001).
Conclusion: Supernumerary and large supernumerary renal arteries were frequently found among the HSK patients on CTA.

Key words: horseshoe kidney, renal artery, CT angiography

INTRODUCTION

Horseshoe kidney (HSK) is a well-known congenital fusion anomaly found in 0.25 % of the general population, and occurs twice as frequently in men than in women [1]. A wide variety of associated anomalies coexist with HSK [2–7]. Arterial anomalies are common, occurring in 60%–80% [1, 2, 6, 8]. HSK presents a special challenge during abdominal aortic surgery due to the complexity of the arterial supply of the isthmus of the HSK [2, 6, 8, 10–15].

Abdominal aortic aneurysm (AAA) is uncommonly found in combination with HSK, presenting in 0.12% of patients undergoing AAA repair [10]. However, evaluation of the renal blood supply is important for adequate surgical planning, especially if considering endovascular aneurysm repair (EVAR) [2, 12–15]. Kaplan *et al*. reported that half of patients performed EVAR with occlusion of accessory renal arteries were found small postoperative infarctions because of an underestimate both in size and number of accessory renal arteries due to limitation of in sensitivity of single helical CT [15]. Therefore they suggest that patients with concomitant AAA and HSK who are considering EVAR should have accessory renal arteries with a maximal diameter of less than 3 mm and without evidence of pre-existing renal failure [15]. Various schema exist attempting to provide a meaningful classification for the renal blood supply in HSK, including the commonly used classification of Eisendrath [2, 9, 10]. However, some authors consider a classification to be impossible due to numerous vascular variations [3, 16]. To our knowledge, no studies have reported the incidence of and variations in renal arteries in patients with HSK using computed tomographic angiography (CTA) with a 64 or 128 multidetector row CT (MDCT), which is known to provide accurate anatomical information of vessels [17–19]. We report the first study investigating the incidence of renal artery anomalies associated with HSK using CTA to classify the renal artery anatomy using the common classification scheme of Eisendrath (Table 1) [10].

METHODS AND MATERIALS

This retrospective study was approved by the institutional review board of our hospital; waiver of informed consent was given due to the retrospective nature of the study. From October 2010 to July 2014, 39 of 28870 patients underwent CTA were found HSKs (Group A). The mean age of patients in Group

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Table 1 Eisendrath classification of the arterial blood supply of a horseshoe kidney

Classification	Description
Type I	one renal artery to each side of the kidney (15%)
Type II	one renal artery to each side of the kidney and an aortic branch to the isthmus (30%)
Type III	two renal arteries to each side of the kidney and one to the isthmus (15%)
Type IV	two renal arteries to each side of the kidney, with one or more arising from the iliac arteries, including the isthmus branch (15%)
Type V	Multiple renal arteries arising from the aorta, mesenteric and iliac arteries (20%)

Table 2 Classification of arterial blood supply of group A

Type	No.	%
I	4	10.3
II	12	30.7
III	1	2.6
IV	0	0
V	22	56.4

A was 60.9 ± 18.8 years; 29 patients were male and 10 were female. In controls, 103 patients with normal kidneys were selected in the same period randomly (Group B). The mean age of patients in Group B was 56.5 ± 12.2 years; 58 patients were male and 35 were female. Patients of group A had CTA performed in the course of evaluation for AAA (N = 8), injury (N = 6), atherosclerosis (N = 5), aortic dissection (N = 2), aortic coarctation with Turner syndrome (N = 1), renal pelvic tumor (N = 1) and other conditions (N = 16). Patients of group B had no aortic disease such as aortic aneurysm, aortic dissection or severe atherosclerosis and had CTA performed for preoperative evaluation of T1 renal cell carcinoma (74 patients) or as part of evaluation for kidney donation (29 patients). Patients of group B without aortic disease were selected because of counting of exact renal artery nomber.This protocol was the standard of care at our institute over the past 5 years and was considered a part of clinical practice that was designed solely to enhance the individual patient's benefit.

CTA was performed using 64 or 128 MDCT scanners of 0.6-mm slice thickness (SOMATOM Cardiac Sensation 64, SOMATOM Definition Flash, SIEMENS, Forscheim, Germany). CTA of the entire abdomen and pelvis was performed using 100−150 mL of iohexol (Omnipaque 300, Daiichi-Sankyo, Tokyo, Japan) at a rate of 4 mL/s, with a scanning delay determined using a bolus tracking method. Other parameters of CTA were 120 kVp, 125 mAs, and 0.5-s rotation time.

Two experienced radiologists interpreted the images, reviewing the axial MDCT images with a 0.5-mm reconstruction interval. Volume-rendered, maximum-intensity projection (MIP) and multiplanar reformatted (MPR) images were used for evaluation of arteries on a dedicated workstations (ZIO station, ZIO Soft, Tokyo, Japan). The number, location and type of the renal arteries, including origin from the aorta or other arteries were assessed. For group A classification of arterial blood supply by Eisendrath was used. We measured the diameter of the short axis of a renal artery at its origin from aorta using curved MPR imaging on the workstation automatically (singo VA 20B, SIEMENS, Muenhen, Germany, Fig. 1). A major single renal artery on each side was standard and other accessory vessels were defined supernumerary arteries. Supernumerary renal arteries greater than 3 mm in diameter were assessed on each side. Any disagreement was resolved and consensus was achieved through discussion.

Demographic data was compared between groups by chi-square test. The incidence of patients with supernumerary renal arteries and supernumerary renal arteries stratified by diameter were compared between the two groups using the chi-square test. P-values < 0.05 were considered statistically significant.

RESULTS

There were no significant differences in demographic data between the two groups (age, p = 0.47; sex, p = 0.45). A total of 403 renal arteries were identified, 155 in Group A, and 248 in Group B. The mean number of renal arteries was 3.87 ± 1.3 in group A and 2.41 ± 0.7 in Group B. The incidence of patients with supernumerary renal arteries was 92.3 % (36/39) in Group A, which was greater than 33 % (34/103) in Group B (p = 0.003). The incidence of patients with supernumerary renal arteries greater than 3mm in diameter was 69.2 % (27/39) in Group A, which was greater than 8.7 % (9/103) in Group B (p < 0.001). The mean size of supernumerary renal arteries greater than 3 mm in diameter in Group A was 4.3 mm and that in Group B was 3.4 mm.

The number and incidence of each type of arterial blood supply in Group A was shown in Table 2. Twenty two patients have isthmic branches from aorta (56.4% : 22/39). Ten aortic branches greater than 3 mm in diameter with early branching in Group A (Fig. 2); in contrast, there was no large aortic branch with early branching in Group B. The isthmic branches arose distal to the inferior mesenteric artery on all 12 cases of Type II anomaly. In patients with type II anatomy, there were 7 large isthmic branches with early branching and those large branches were distal to the inferior mesenteric artery .Ten arteries arose from common iliac arteries on 21 patients (53.8% : 21/39) with Type V anomaly (Fig. 3); in contrast, only one artery arose from the common iliac artery in Group B patients. One patient in Group A had maximum 8 renal arteries (Fig. 4).

Eight patients with AAA in Group A had supernumerary renal arteries. Seven patients with AAA were

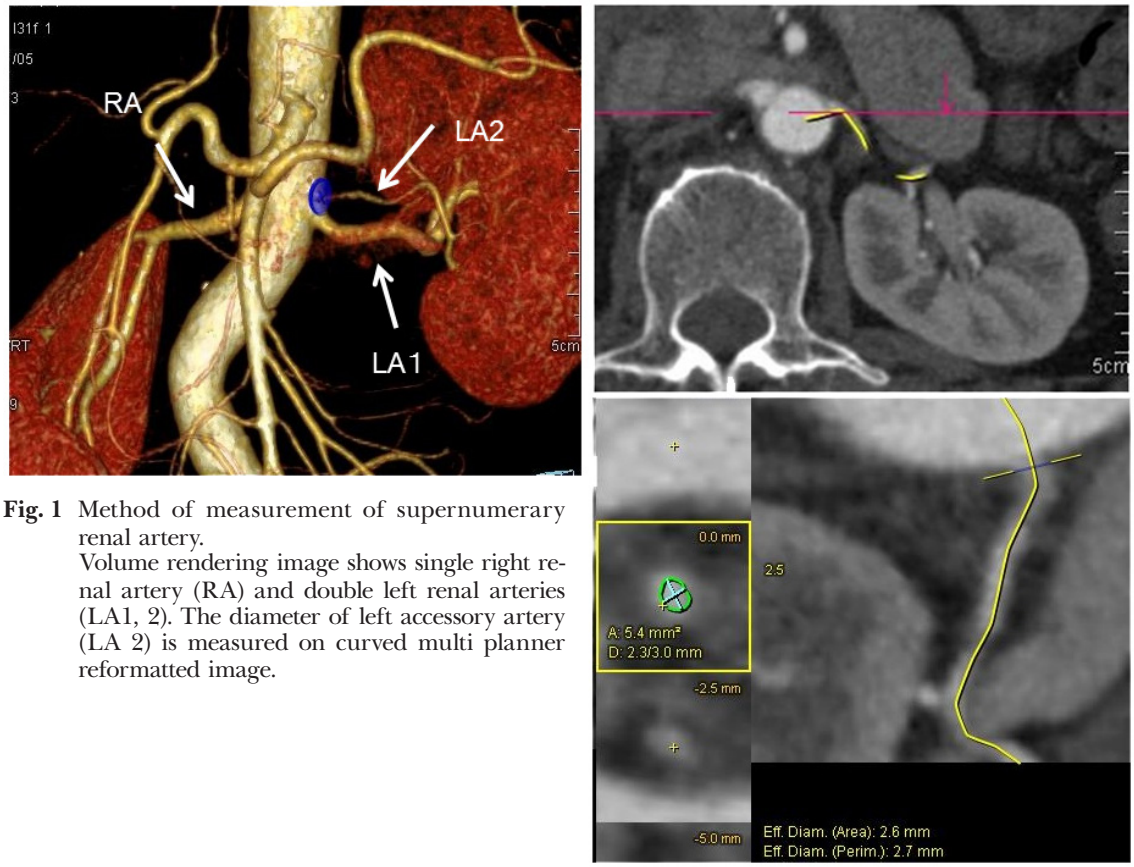

Fig. 1 Method of measurement of supernumerary renal artery.
Volume rendering image shows single right renal artery (RA) and double left renal arteries (LA1, 2). The diameter of left accessory artery (LA 2) is measured on curved multi planner reformatted image.

type II anomalies with large isthmic branch greater than 3 mm in diameter arose from the aortic aneurysms. Those large isthmic branches arose from the anterior wall of aneurysm on 5 HSK patients. One large isthmic branch arose from the posterior wall of aneurysm on 1 HSK patients (Fig. 2). On 1 HSK patient, the isthmic branch arose from the lower end of AAA, and was just above the aortic bifurcation. All large isthmic branches greater than 3 mm in diameter on patients with AAA arose from distal to inferior mesenteric artery. One patient with AAA was type V anomaly.

DISCUSSION

HSK is a well-known congenital anomaly of the upper urinary tract observed with an incidence of one in 400–800 live births [1]. HSK results from the fusion of metanephric buds between weeks 4 and 8 of embryogenesis, preventing their cephalic migration and normal rotation [1, 6, 20]. The inferior mesenteric artery prevents the cranial migration of the isthmus of the fused kidney, which remains in the lower part of the abdomen [1, 20, 21]. Typically, the urinary collection system is displaced anteriorly, with the ureters lying anterior to the isthmus [1, 20, 21].

A wide variety of associated genitourinary and non-genitourinary anomalies are associated with horseshoe kidney [2–7]. Renal vascularization is abnormal in two-thirds of cases [1, 2, 6, 8].The main renal arteries generally develop normally. In addition, mesonephrogenic arteries often persist to vascularize the upper part of the kidney, while the inferior segmental metanephric arteries supply the lower portion of the kidney [20]. The existence of supernumerary arteries in HSK reflects the continuously changing blood supply to the developing kidney the course of its ascent from the pelvis to its final position [21]. A typical HSK shows great variation in origin, number, and size of the arteries due to retention of primitive vessels [16].

The incidence of supernumerary renal arteries in a normal kidney shows variability from 9 %–76 % and is generally between 28 %–30 % in anatomic and cadaver studies [22–24]. In contrast, the incidence of supernumerary renal arteries in patients with HSK was reported as 60 %–81 %, significantly higher than that of the general population [1, 2, 6, 8]. In an autopsy study of 139 patients with HSK, the incidence of supernumerary renal arteries was reported as 81 % [8]. In our study, the incidence of supernumerary renal artery in patients with HSK and normal kidneys was 92.3 % and 33 %, respectively; the incidence of supernumerary renal arteries that we found in HSK patients was slightly higher than previously reported. This may be due to small sample size of present study.

It is believed that in HSK cases, Eisendrath Type II anomaly, e.g. one renal artery for each side with an aortic branch to the isthmus, is common (Table 1) [12], however anomalous vessels may vary in number and location [2, 10, 16]. In our series, the most common anatomic variant was Eisendrath Type V anomaly (Table 2). The reason of those differences was unclear. We observed quite variables blood supply to the isthmic region. In one case, a large isthmic branch arose from the dorsal wall of the aorta (Fig. 2). From these results, we agree with Stroosma's opinion that these frequently occurring anatomic variations preclude a simple classification [16].

On Review article by Stroosma *et al.*, the mean

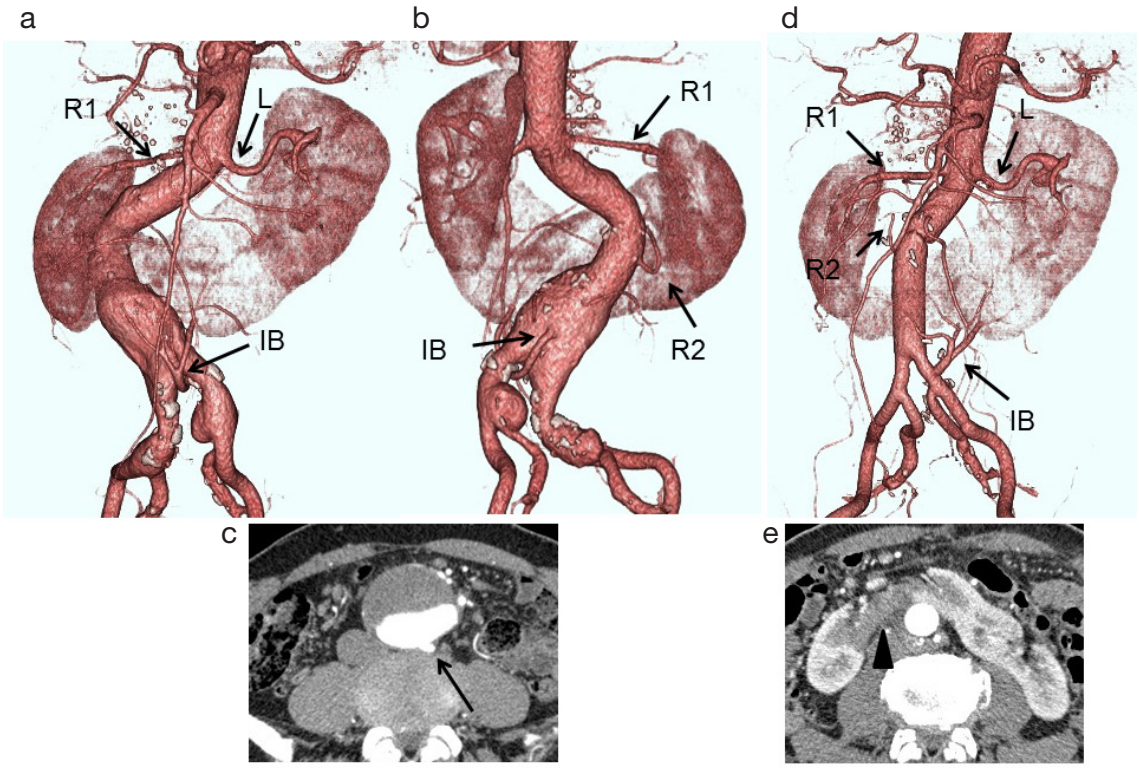

Fig.2 69-year-old male patient with abdominal aortic aneurysm and horseshoe kidney. Volume-rendered images (a, b) show 4 renal arteries, the abdominal aneurysm, and bilateral common iliac artery aneurysms. Axial CT image (c) shows a large isthmic branch with early branching arising from the dorsal wall of the abdominal aneurysm (arrow). Y graft replacement was selected due to a large isthmic branch rather than endovascular aneurysm repair. Volume-rendered image (d) after Y-graft replacement shows repair of an isthmic branch arising from graft of the left common iliac artery; however, a right second renal artery is stenotic compared with the preoperative image. Axial CT image (e) reveals renal infarction (arrowhead) territory in the right second renal artery. R1: right first renal artery, R2: right second renal artery, L: left renal artery, IB: isthmus branch.

number of renal arteries was 3.9 of HSKs diagnosed on operation [25]. On our study the mean number of renal arteries in HSK patients was 3.87. The accuracy of 16-MDCT in the evaluation of renal arteries has ranged from 93 % to 100 % in several reports [17–19]. In our experience, CTA using more than 16 multidetectors enabled excellent preoperative detection of arterial anatomy. Therefore, there was no difference between Stroosmas' and our results of the mean number of renal arteries.

Several surgeons have reported the impact of HSK on aortic surgery [2, 6, 8, 10, 11]. HSK poses technical difficulties during open repair of abdominal aortic aneurysms because it limits access to the distal aorta, the presence of multiple arteries, and anteriorly located ureters [2, 8, 10, 11]. Combined with the information obtained from more than 64 MDCT, CTA is useful in planning surgical procedures and preventing complications [19]. In this study, one patient with AAA underwent Y-graft replacement because of a large isthmus branch and an isthmus branch was repaired arising from the left common iliac arterial graft. Unfortunately, small renal infarction occurred in territory of right second renal artery (Fig. 2), as would be expected due to the segmental arterial supply with poor collateralization between segments [2]. However the patient's renal function was normal because of occlusion of a small supernumerary renal artery.

EVAR has been reported to repair AAA in a minimally invasive fashion [12–15]. The advent of EVAR presents new options for dealing with the anomalous renal vessels characteristic of HSK. Studies report that accessory renal arteries may be safely covered by the endograft with minimal postoperative consequence [12, 13]. However, this assumption is based on normally placed main renal arteries and supernumerary vessels of less than 3 mm diameter [12, 14]. It has been reported that non-dominant supernumerary renal arteries to the isthmus that are less than 3 mm in diameter can be covered without any problem [12]. However, covering larger supernumerary arteries can lead to type II endoleak, which is caused by retrograde flow through collateral vessel into the aneurysm, or renal infarction [23]. To our knowledge, this was the first study of evaluation of size of renal artery on HSK patients. In our study, 69.2 % of HSK patients had supernumerary renal arteries greater than 3 mm in diameter and the mean size of supernumerary renal arteries greater than 3 mm in diameter was 4.3 mm. Ruppert *et al.* reported that Type V anomaly not be repaired with EVAR [12]. On our study, half of HSK cases had Type V anomaly. A case of hybrid repair combined EVAR and open surgical repair of large supernumerary renal artery was reported because large supernumerary renal arteries and supernumerary renal arteries that perfuse a large portion of the renal parenchyma should be preserved

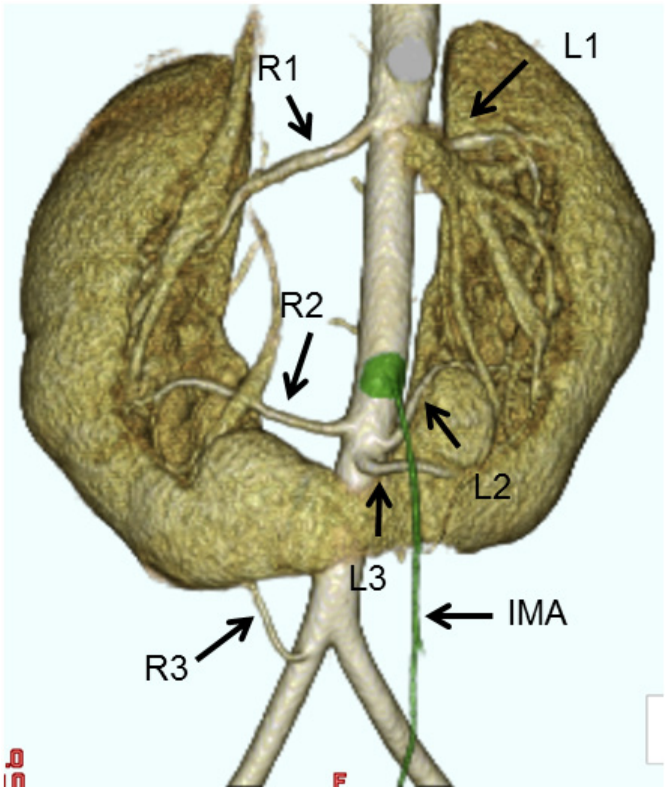

Fig. 3 18-year-old female patient with Turner's syndrome and horseshoe kidney Volume-rendered image shows 6 renal arteries, the third right renal artery arises from the right common iliac artery and the patient is classified as having Type V anatomy. The celiac, superior mesenteric, and lumbar arteries are not shown. R1: right first renal artery, R2: right second artery, R3: right third renal artery, L1: left first renal artery, L2: left second renal artery, L3: left third renal artery, IMA: inferior mesenteric artery.

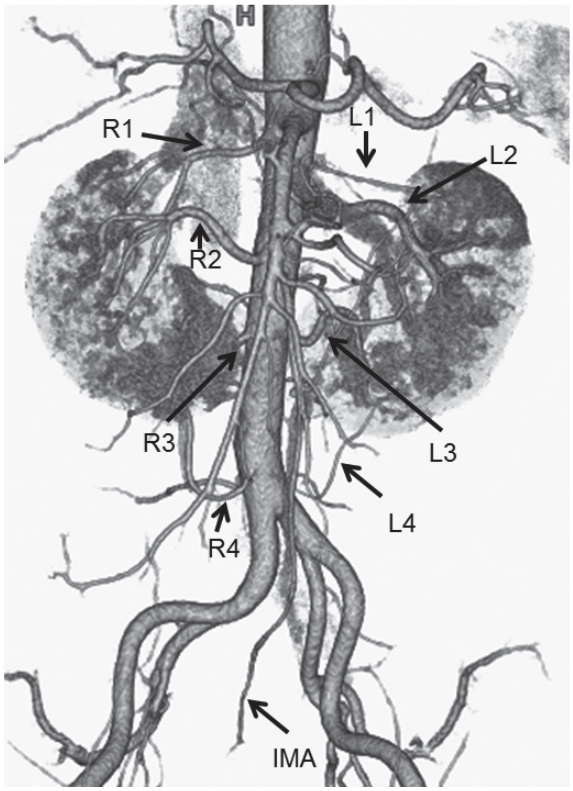

Fig. 4 69-year-old male patient with horseshoe kidney. Volume-rendered image shows 8 renal arteries arising from abdominal aorta. Bilateral second renal arteries are main feeding arteries, however right first and bilateral third arteries are greater than 3 mm in diameter.
R1: right first renal artery, R2: right second artery, R3: right third renal artery, R4: right firth renal artery, L1: left first renal artery, L2: left second renal artery, L3: left third renal artery, L4: left firth renal artery, IMA: inferior mesenteric artery.

[26]. In the case of dominant accessory renal artery greater than 3 mm in diameter, Rupper *et al.* recommended diagnostic use of selective angiography to determine what proportion of the HSK and how much parenchyma was supplied by the accessory renal artery [12]. We propose that prior to EVAR selective angiography should be performed how much parenchyma is supplied by the supernumerary artery for patients with type V anomaly found on CTA. Suitability for EVAR should be decided on a case by case basis in equivocal case.

Our study has several limitations. First, the sample was small. Second, detailed branching of renal arteries was not evaluated due to the narrowing of the renal hilum caused by the isthmus in HSK. Third, there was no EVAR case. Forth, surgical confirmation of arterial anatomy was not possible, as this was a retrospective study. A larger study examining correlations between CTA and surgical findings would be necessary to determine the true incidence of renal artery anomalies in patients with HSK.

In conclusion, the overall incidence of supernumerary renal arteries in patients with HSK was 92.3% using CTA. The incidence of renal artery anomalies with HSK is significantly higher than that of a normal kidney. CTA by 64 or 128 MDCT is useful in the detection of renal artery anomalies, and its routine use should promote awareness of these anomalies and reduce potential complications during operations.

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