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Renal Artery Perfusion Evaluation Before Transplantation via a 3-Dimensional Image Analysis System

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Background: The perfusion areas of renal arteries in renal transplantation are assessed via subjective observations during perfusion in a bench surgery; however, this evaluation method lacks reliability and objectivity. In this study, we aimed to evaluate the perfusion area of each main and side artery kidney graft using a 3-dimensional (3D) image analysis system.

Methods: We enrolled 50 patients who had undergone living kidney transplantation with multiple renal artery grafting at our center between 2005 and 2017. All computed tomography images from donors were retrospectively analyzed using a 3D image analysis system. We then calculated the artery perfusion areas associated with the artery reconstruction method used.

Results: The perfusion areas of side arteries, which were evaluated after surgery, were statistically different among cases employing different reconstruction methods ($P < 0.001$). The perfusion area of the ligated side arteries (volume, 10 mL; proportion, 6.1%) was smaller than that of the ligated side arteries where different reconstruction methods were used.

Conclusion: A 3D image analysis system could provide an accurate visual representation of the vasculature prior to living donor transplantation. It could also enable calculation of perfusion area for each artery and preoperative prediction of the need for arterial

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reconstruction, thereby promoting safe kidney transplantation surgery.

Key words: Perfusion – Renal artery – Kidney transplantation – Image analysis system

Currently, multiple renal artery grafting during kidney transplantation is possible.[1,2] Extremely small accessory arteries can be ligated without damaging the graft.[3] Different institutions have different strategies for the surgical management of kidney transplantation with multiple renal arteries.[4] However, in most cases, the evaluation of the perfusion area is performed via subjective observations during donor nephrectomy or bench surgery by temporary clamping of the accessory arteries. The determination of perfusion area through observations during surgery lacks reliability and objectivity, although the optimal method to visualize the blood vessels before surgery has not been established.

In our study, we aimed to investigate the use of a 3-dimensional (3D) image analysis system for kidney transplantation surgery; in particular, we aimed to evaluate the perfusion area of the main and side arteries in multiple-artery kidney grafts using a 3D image analysis system before kidney transplantation surgery.

Patients and Methods

Patients

A total of 50 consecutive cases of living donor kidney transplantation with multiple renal artery performed at Tokyo Medical University Hachioji Medical Center from May 2005 to January 2017 were included. Renal transplantations from deceased donors were not included. A retrospective review of the morphologic findings of the kidney graft and the medical records of both the recipients and donors was conducted.

Surgical procedure

Bench surgery

We reconstructed as many side arteries as possible, especially the inferior polar artery, which allowed blood perfusion to the ureter. Small side arteries, which were difficult to reconstruct and had less than 10% perfusion to the kidney graft during bench surgery, were ligated.

Recipient's surgery

The following 4 different reconstruction methods were used: the conjoined method, which created a common orifice between 2 arteries (Fig. 1a); the side-to-end method, wherein the side artery was anastomosed to the main artery wall (Fig. 1b); the individual method, wherein the main and side arteries were anastomosed individually (Fig. 1c); and the ligation-alone method, wherein the side artery was ligated. A combination of any of these methods was classified as another group. The reconstruction method was selected by each surgeon based on the condition of the renal arteries. All main and side arteries, including the reconstructed arteries of the kidney graft, were side-to-end anastomosed to the external iliac artery of the recipient.

3D image construction

All living kidney transplant donors underwent a dynamic enhanced computed tomography (CT) scan before surgery. Images were obtained with a 64-multidetector row CT scanner (LightSpeed VCT, GE Healthcare, Milwaukee, Wisconsin) with 1.25-mm thickness. A contrast medium was administered (dose, 1.4–1.6 mg/kg) through a peripheral venous catheter. Scanning in the early, late, and urinary phases was performed at approximately 30, 45, and 150 seconds, respectively.

All CT images were retrospectively analyzed with a 3D image analysis system (Synapse Vincent, Fuji Medical Systems Inc, Tokyo, Japan). The volume of the kidney, number of renal arteries, diameter of each artery, and perfusion area were assessed in detail.

In 3D image analysis, the following steps were performed:

1. Kidney extraction: The kidney was semiautomatically extracted using the region growing method with minor manual modifications (Fig. 2a).
2. Extraction of vessels: Renal arteries, veins, and ureters were extracted from the images (Fig. 2b) and visualized after the renal parenchyma was made transparent (Fig. 2c).
3. Evaluation of each artery construction and its perfusion area: The volumetric analysis was used to calculate the perfusion area (Fig. 2d).

In a sample case, the side artery was ligated because its perfusion was less than 10%. After reperfusion of the graft during surgery, a partially ischemic area in the graft was detected, which was similar to that found in the 3D simulation before surgery (Fig. 2e).

Statistical analysis

Differences were determined using bivariate tests, including Pearson χ^2 and Fisher exact tests, for nominal variables. Student *t*-test was used to compare quantitative variables, whereas the Mann-Whitney *U* test was used to compare continuous or ordinal data. The Kruskal-Wallis test was performed to compare the different outcomes among the reconstruction methods. All statistical analyses were performed using the SPSS software version 24.0 (SPSS Inc, Chicago, Illinois). Statistical significance was set at $P < 0.05$.

Informed consent to use all medical records, including CT scanning images, was obtained from all patients. The Institutional Review Board of Tokyo Medical University Hachioji Medical Center approved this cross-sectional retrospective study (approval number: H-260).

Results

Patient characteristics

Donors had a mean age of 52.5 years. The number of renal arteries identified was 2 in 44 cases (88.0%), 3 in 5 cases (10.0%), and 4 in 1 case (2.0%). The preoperative and postoperative information for each reconstruction method is shown in Table 1. The number of cases was 16 (31.6%) for the conjoined method, 9 (16.4%) for the side-to-end method, 13 (27.6%) for the individual method, 10 (20.2%) for the ligation alone, and 2 (4.1%) for the combined method. The conjoined + side-to-end case had 4 arteries before reconstruction (Fig. 3).

Surgical information

Warm ischemic time was not statistically different among the reconstruction methods ($P = 0.858$). However, a statistically significant difference in cold ischemic time and total ischemic time between the methods ($P = 0.005$ and 0.013, respectively) was found. The mean cold ischemic time and total ischemic time of the individual anastomosis and ligation-alone groups were shorter than those of the other groups, whereas the combination group had longer cold ischemic time and total ischemic time.

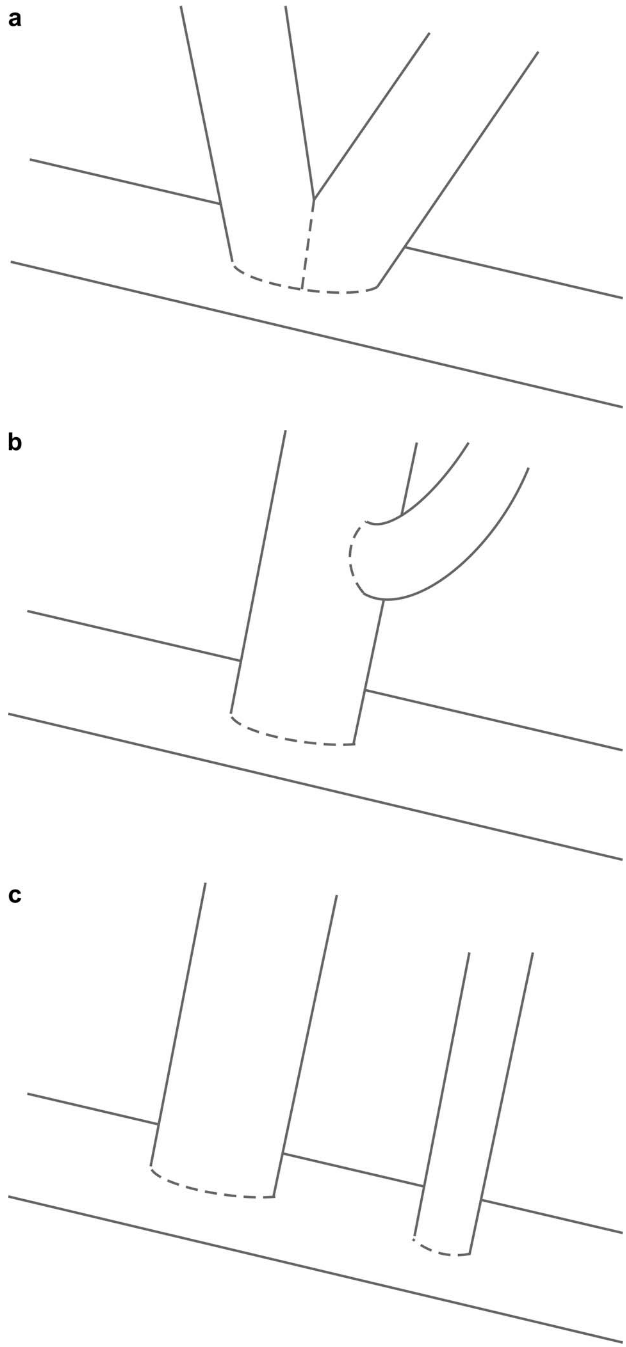

Fig. 1 Reconstructive methods used for multiple renal arteries: (a) conjoined, (b) side-to-end, and (c) individual.

Arterial diameter and perfusion volume

Table 2 shows the diameters and perfusion areas of all main and side renal arteries. The mean volume and proportion of the perfusion area of main arteries were 131 mL and 79.7%, respectively. The side arteries were classified according to the anastomosis

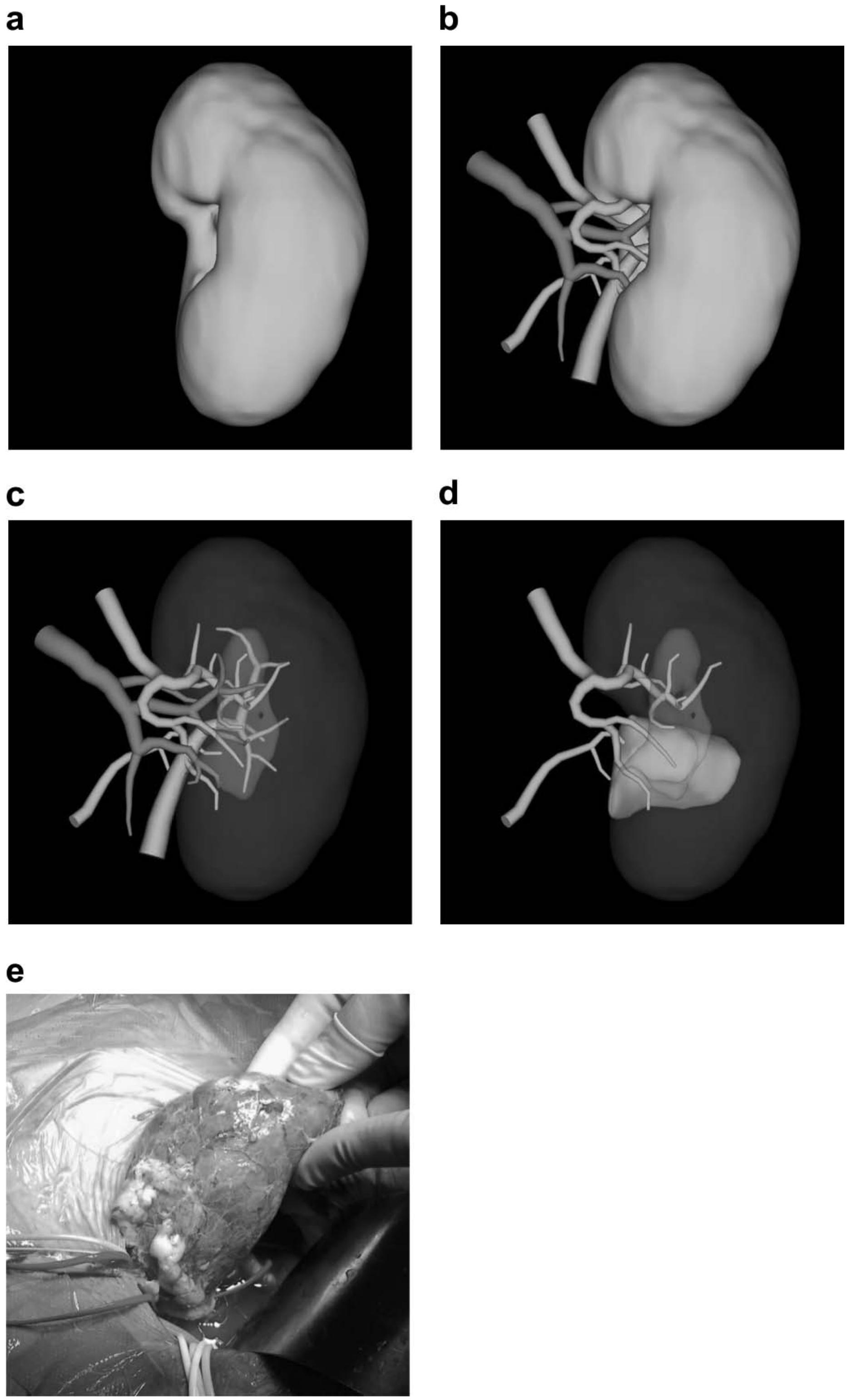

Fig. 2 Illustration of a multiple renal artery graft using a three-dimensional image analysis system (Synapse Vincent®): (a) kidney extraction, (b) extraction of vessels, (c) visualization of vessels, (d) volumetry of the perfusion area, and (e) intraoperative photograph.

Table 1 Preoperative and postoperative information for each reconstructive method used for kidney grafting[a]

Characteristics	All patients (n = 50, 100%)	Conjoined method (including conjoined + ligation) (n = 16, 32%)	Side-to-end method (including side-to-end + ligation) (n = 9, 18%)	Individual method (n = 13, 26%)	Ligation alone (n = 10, 20%)	Combination of each method (n = 2, 4%)	*P* value
Donor kidney							
Weight, g	171	178	167	166	162	211	0.751
Volume, using Vincent, mL	164	167	159	166	161	180	0.593
Operative time							
Warm ischemic time, min	9	12	5	7	8	7	0.858
Cold ischemic time, min	125	138	147	105	97	185	0.005
Total ischemic time, min	134	151	152	113	106	192	0.013
Arterial anastomotic time, min	30	26	39	37	20	30	0.232
First urine time, min	36	25	70	27	40	31	0.624
24-hour Ccr of 14 POD	48.9	59.4	44.6	47.1	46.9	29.7	0.396
Serum creatine of 1 POM (g/dL)	1.3	1.5	1.3	1.2	1.1	1.7	0.586

Ccr, creatinine clearance; POD, postoperative date; POM, postoperative month.

[a]Data are presented as the mean. Kruskal-Wallis test was used when appropriate. Warm ischemic time is time from cross-clamp until perfusion completion; cold ischemic time is time from perfusion completion until reperfusion.

method. A statistically significant difference in the diameter between the side arteries was noted ($P = 0.003$).

A statistically significant difference in the perfusion area (both volume and proportion) between the anastomosis methods was observed (both $P < 0.001$). Perfusion was lower in the ligated arteries than in the other reconstructed arteries.

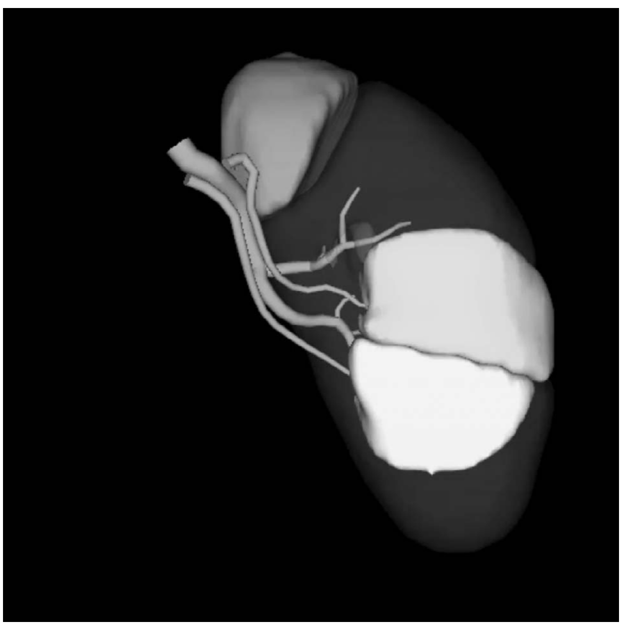

Fig. 3 Illustration of a case involving four renal arteries.

Postoperative course

The patency of the reconstructed arteries was monitored using ultrasound when necessary, and the patients had no reconstructed artery complications. Postoperative graft evaluation on the basis of 24-hour creatinine clearance was performed after 14 days, and the serum creatinine level was determined 1 month after the transplantation; no statistically significant difference ($P = 0.396$ and 0.586, respectively) was observed.

Discussion

In this retrospective analysis, we were able to measure artery perfusion using 3D images of the renal arteries obtained before transplantation. The 3D image analysis system is commonly used in other organ surgeries, such as liver surgery. The separation line of the perfusion area in Synapse Vincent volumetry is calculated on the basis of the distance between 2 adjacent arteries. Its accuracy has already been confirmed in liver surgery.[5]

To our knowledge, this is the first study that uses a 3D image analysis system for the surgical simulation of renal transplantation. Our results showed that the 3D image analysis system enables preoperative visualization of the renal graft, including the vessels running, and arterial perfusion volume measurement. Evaluating the perfusion area before surgery promotes a safer kidney transplantation surgery. In donor surgery, ligation of side arteries determines the difficulty of the operation.[6]

Table 2 Diameter and supply region of each renal artery[a]

Characteristics	Main arteries (n = 50)	Side arteries				*P* value
		Conjoined (n = 19)	Side-to-end (n = 11)	Individual (n = 13)	Ligation (n = 14)	
Diameter, mm	4.5	2.9	2.7	2.1	1.6	0.003
Supply region, mL	131	43	31	31	10	<0.001
Supply region, %	79.7	25.3	18.5	18.7	6.1	<0.001

[a]Data are presented as the mean. Kruskal-Wallis test was used when appropriate.

In recipient surgery, thin upper pole artery ligation contributes to an easier and safer operation.[7] To address these challenges, standard criteria or rules for side artery ligation in kidney transplantation will be needed. In the future, our 3D image analysis system may contribute to clarification of the limitation of side artery ligation. In addition, the 3D image analysis system may be applicable to renal artery repair, including ex vivo renal artery reconstruction and autotransplantation.[8]

One limitation of this study was that we were not able to assess whether the renal side artery enables perfusion to the ureter. Hence, another visualization method is needed for ureter perfusion evaluation. Nakamura *et al*[9] reported the effectiveness of an intraoperative near-infrared fluorescence camera system, which could visualize ureter perfusion during kidney transplantation.

In conclusion, we introduced a novel 3D image analysis system for the surgical simulation of living donor kidney transplantation with multiple renal artery graft. The 3D image analysis system helps visualization of the relationships among the renal artery, vein, and ureter before surgery. Furthermore, the perfusion area of each artery could be calculated, and the need for arterial reconstruction could be predicted preoperatively, thereby promoting safe kidney transplantation surgery.

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