ORIGINAL ARTICLE

Comparison of live donor predonation and post-transplant kidney volumes and glomerular size in pediatric patients weighing less than 15 kg – a retrospective study

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ABSTRACT

Renal transplantation of adult-size kidneys presents a size mismatch in small children. This study presents a comparison of live donor predonation and recipient post-transplant kidney volumes (k-vol) and glomerular size at 1 year after transplantation. We analyzed 47 pediatric renal transplant recipients weighing <15 kg between 2009 and 2017. The k-vol before and 1 year after transplantation and glomerular size at implant and 1 year post-transplant were evaluated. We estimated the relationships between these changes and graft function, and the factors associated with k-vol. Pretransplant k-vol was 158.1 ± 25.1 ml, and the k-vol at 1 year post-transplant was significantly reduced by −17.2% to 132.3 ± 27.3 ml ($P < 0.001$). Implant glomerular size showed the diameter was 165.3 ± 15.1 μm and the area 20 737.1 ± 3230.6 μm^2. One-year post-transplant, the glomerular diameter was 150.6 ± 11.4 μm and the area 17 428.3 ± 2577.9 μm^2, significantly reduced compared with implantation values (both $P < 0.001$). The change in k-vol was affected by pretransplant abdominal cavity (ml/200 ml cavity volume, partial regression coefficient = 0.029, SE = 0.009, $P = 0.004$) and recipient's weight gain (ml/5% of weight gain, partial regression coefficient = 0.020, SE = 0.006, $P = 0.002$). In small pediatric transplants, an adult-size kidney is acceptable with reduction in k-vol. Moreover, the post-transplant k-vol might be regulated by pretransplant physique and post-transplant somatic growth.

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Key words
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Introduction

Renal transplantation is the optimal treatment for children with end-stage renal disease when considering their growth, quality of life, and schooling. In pediatric transplantation for small recipients, many recipients have received an adult-size kidney owing to the shortage of pediatric deceased donors [1]. As the result, there is

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physiological discrepancy between the recipient's physique and the adult-size kidney, and the small recipients need to accept the large kidney through volumetric and functional adaptation. However, little is known about how an adult-size kidney can become accommodated in small pediatric recipients.

The adult-size kidney carries advantages and disadvantages for small pediatric recipients. There is a greater nephron mass-by-size mismatch between a smaller physique and an adult-size kidney. This effect presents sufficient renal function for the small recipients. However, it is unclear whether the supply of blood flow to an adult-size graft is optimal in preventing relative hypoperfusion. In addition, adult-size kidneys are too large and mismatched to occupy the recipient's small abdominal cavity. As a result, renal allograft compartment syndrome (RACS) has been reported as one of the reasons for poor allograft perfusion by graft compression caused by high pressure [2–5].

Kidneys have high propensity for size variation. In adult transplants, transplanted graft volume was increased between pre- and post-transplant at a rate of 27.3% [6]. The elevation of the volume was speculated to be glomerular hyperfiltration of a single kidney. By contrast, adult-size kidneys in pediatric recipients shrunk by 26–31% [7,8], and the grafts needed to surmount the limited blood supply of the small physique and the compression arising from shortage of abdominal space. The aim of this study was to estimate the changes in kidney volume (k-vol) and glomerular size of pediatric kidney transplant recipients pre- and post-transplant. The associations between the changes in k-vol, glomerular size, and graft function were also evaluated.

Materials and methods

Patient population

Fifty-one consecutive pediatric transplant recipients weighing less than 15 kg received a live donor kidney transplant at our center between March 2009 and December 2017. All were primary transplants without donor-specific antigen. After excluding the recipients ($n = 4$) who did not receive a computed tomography (CT) scan at 1 year post-transplant, 47 patients were enrolled in this study. We evaluated the changes in k-vol before and 1 year after transplantation. Glomerular size was also analyzed in implant and 1-year post-transplant protocol biopsies (PBx). We examined the relationships between these changes and graft function during the first year after transplantation. Moreover, possible factors associated with the change in k-vol were studied. The study protocol conformed to the Declaration of Helsinki and was approved by the Toho University Omori Medical Center institutional ethics committee (approval number M18208).

Data collection

From the medical records, we retrospectively collected information regarding demographic data of the recipient and donor. We recorded information on the clinical course after transplantation, such as the time of initial urine output and estimated glomerular filtration rate (eGFR). All patients were followed in our unit; the follow-up period ran from transplantation to the time of obtaining 1-year post-transplant PBx. Follow-up data included height, weight, and graft function of recipients.

Pretransplant kidney volume and abdominal cavity in recipients

Multislice helical CT was performed for all recipients and donors. The measurement of the pretransplant k-vol, the pretransplant recipient's abdominal cavity (R-aCav) volume, and post-transplant k-vol was estimated with 5-mm reconstructed slice thicknesses. Pretransplant CT was performed for recipients after drainage of intraperitoneal fluid when the recipient received peritoneal dialysis. Post-transplant CT was performed just before undergoing 1-year post-transplant PBx. The predonation k-vol, pretransplant abdominal cavity, and post-transplant k-vol were calculated automatically using Virtual Place image-recognition software (AZE, Tokyo, Japan), which traced the edge of each kidney and each abdominal cavity on cross-sectional three-dimensional CT images. For definition of the abdominal cavity volume, the craniocaudal limit of the abdominal cavity was obtained from the first axial slice of the diaphragm to the last axial slice of the coccyx. The transverse limit measurement was the peritoneum of each side of the abdominal cavity. The anterior to posterior limit was the line of the muscle groups to the transverse processes of the vertebrae.

Measurement of glomerular size

All specimens of implant biopsy (1 h after reperfusion) and 1-year post-transplant PBx were formalin-fixed, and hematoxylin–eosin and periodic acid–Schiff were used for staining. The imaging of glomerular profiles was performed using optical microscopy (magnification of 200×), and the cellSens imaging analysis system (Olympus, Tokyo, Japan) was used for the measurement of

glomerular size. The profile of diameter of glomeruli was measured according to a previous report [9]. Mutually perpendicular longest diameters were measured, and the mean value of the two diameters was calculated. The glomerular edge was traced and the area calculated. The overall largest three glomeruli that did not exhibit focal or global sclerosis were measured in each slide; mean diameters and mean areas in the three glomeruli were calculated.

Definitions

The eGFR was estimated using the equations for Japanese pediatric patients [10]. We used the percentage change in k-vol, glomerular size (diameter and area), eGFR, and height and weight from the baseline per year (Δk-vol, Δdiameter, Δarea, ΔeGFR, Δheight, and Δweight) to express the progression. The change (Δ) was calculated by applying the following formula:

$$\Delta(\%) = [(\text{each value at 1 year post} - \text{transplant}) - (\text{each value at transplant})] \times 100/(\text{each value at transplant}).$$

Immunosuppressive therapy

The immunosuppression protocol administered to all patients before transplantation consisted of a calcineurin inhibitor (cyclosporine or tacrolimus), mycophenolate mofetil, and steroid. Monoclonal anti-CD25 antibody was administered for induction. Rituximab was used for ABO-incompatible transplantation at days −1 and −10 pretransplant, with or without plasmapheresis. Cyclosporine was adjusted to maintain the area under the concentration curve 0–4 of 3000–3500 ng × h/ml (target trough level 150–250 ng/ml) for the first 3 months and 2000–2500 ng × h/ml from then until 1 year post-transplant. The target trough level for tacrolimus was 10–13 ng/ml for the first month, 7–10 ng/ml for the next 3 months, and 5–6 ng/ml after 4 months. Mycophenolate mofetil was given at a dose of 600–1200 mg/m^2/day. Prednisolone 20 mg/day was tapered to a maintenance dose of 4 mg/day until 5 weeks post-transplant and then was switched to alternate-day administration.

Statistical analysis

All values shown are median [interquartile range (IQR)], mean and standard deviation, or percentage. Continuous variables were compared using Student's t-test. The correlation between pretransplant and post-transplant k-vol and the implant and post-transplant glomerular size as well as graft function were analyzed. The factors for the reduction in k-vol were analyzed by partial regression coefficient (β) with standard error (SE) using simple linear regression analysis and multiple regression analysis. The differences were considered statistically significant at $P < 0.05$. The data were analyzed using JMP software, version 13 pro (SAS Institute, Cary, NC, USA).

Results

Patients' growth and clinical course

In recipients, the mean age, height, and weight at the time of transplant were 4.3 ± 1.8 years old, 89.7 ± 9.4 cm, and 11.8 ± 2.0 kg, respectively (Table 1). Pretransplant R-aCav volume was 1771.9 ± 454.3 ml in recipients. All donors were related, and the mean age, height, and weight at the time of transplant were 37.8 ± 7.2 years old, 163.6 ± 8.9 cm, and 61.2 ± 9.8 kg, respectively.

Transplant approaches were intraperitoneal in 21 cases and extraperitoneal in 26 cases. In all transplants, initial urine was expressed until the end of the operation, and the time of initial urine was 23 min (IQR 12–47). Administration of antihypertensive agents was necessary in nine cases (19.1%), calcium blocker in six cases, angiotensin II receptor blocker in one case, and both calcium blocker and angiotensin II receptor blocker in two cases. Three patients experienced clinical acute rejection with increasing serum creatine within 1 year post-transplant; diagnostic biopsies revealed antibody-mediated rejection at 29 days post-transplant in one, borderline changes at 40 days post-transplant in one, and T-cell-mediated rejection at 8 months post-transplant in one.

At 1 year post-transplant, the mean height and weight were 97.6 ± 8.3 cm and 14.4 ± 3.2 kg, respectively. The rates of increase were thus 8.6% (IQR 7.0–12.0) in height and 20.5% (IQR 14.0–31.7) in weight. Biopsy-proven subclinical acute rejection by 1 year was observed in four cases (all involved T-cell-mediated rejection).

Change in kidney volume

Pretransplant k-vol was 158.1 ± 25.1 ml, and this volume depended on donor weight ($r = 0.633/<0.001$) and height ($r = 0.587/P < 0.001$) and differed by donor

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Table 1. Baseline and post-transplant characteristics.

	Implant	1 year post-Tx
Recipient gender (M/F)	25/22	–
Recipient age (year)	4.3 ± 1.8	–
Recipient height (cm)	89.7 ± 9.4	97.6 ± 8.3
Recipient weight (kg)	11.8 ± 2.0	14.4 ± 3.2
Recipient BSA (m^2)	0.53 ± 0.07	0.61 ± 0.09
Recipient BMI (kg/m^2)	14.7 ± 1.9	15.0 ± 1.8
Pre-Tx aCav (ml)	1771.9 ± 454.3	–
Donor gender (M/F)	29/18	–
Donor age (year)	37.8 ± 7.2	–
Donor height (cm)	163.6 ± 8.9	–
Donor weight (kg)	61.2 ± 9.8	–
Donor BSA (m^2)	1.66 ± 0.16	–
Donor BMI (kg/m^2)	22.8 ± 2.7	–
Tx k-vol (ml)	158.1 ± 25.1[a]	132.3 ± 27.3[a]
Male (donor)	174.2 ± 22.5[b]	137.9 ± 6.4
Female (donor)	148.0 ± 21.3[b]	128.8 ± 5.0
Recipient weight (kg)/ donor weight (kg), (%)	19.6 ± 4.1	–
Pre-Tx k-vol (ml)/ pre-Tx recipient's aCav (ml), (%)	9.4 ± 2.4	–
Pre-Tx renal replacement therapy		
Preemptive	9	
PD	33	
HD	1	
HD before PD	2	
PD before HD	2	
Tx approach (intra-/ extraperitoneal)	21/26	
Warm ischemic time (min)	3 (2–4)	
Cold ischemic time (min)	71 (55–93)	
Secondary warm ischemic time (min)	41(34–48)	
Initial urine output (min)	23 (12-47)	
Clinical acute rejection within 1 year post-Tx		3 (6.4%)
Subclinical acute rejection (1-year post-transplant protocol biopsy)		4 (8.5%)

aCav, abdominal cavity; BMI, body mass index; BSA, body surface area; HD, hemodialysis; k-vol, kidney volume; PD, peritoneal dialysis; Tx, transplant.

[a,b]Significant at $P < 0.001$.

gender (male 174.2 ± 22.5 ml and female 148.0 ± 21.3 ml, $P < 0.001$). The ratio between pre-transplant k-vol and pretransplant R-aCav volume was 9.4 ± 2.4%. The k-vol at 1 year post-transplant was significantly reduced to 132.3 ± 27.3 ml ($P < 0.001$, Table 1). The Δk-vol was −17.2% (IQR −26.6 to −8.4), and 40 cases (85.1%) experienced reduction of k-vol and seven cases (14.9%) had increased k-vol. However, no difference in k-vol between donor genders was observed after 1 year. The relationship between the Δk-vol and pretransplant k-vol/pretransplant recipient's weight showed that the high ratio of pretransplant k-vol/pretransplant recipient's weight was more likely to show reduction of k-vol with a significant negative correlation (Fig. 1; $r = 0.421$, $P < 0.005$).

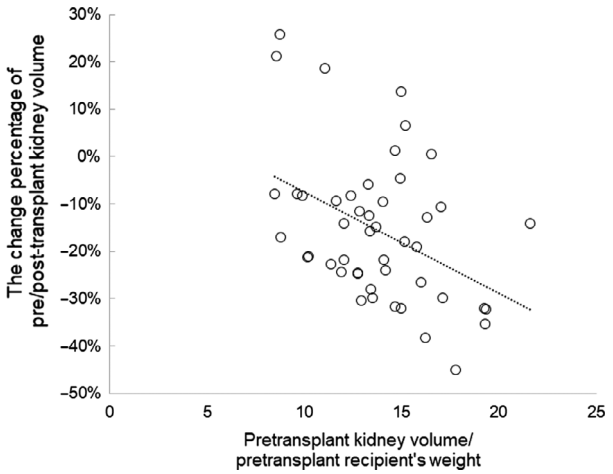

Figure 1 Relationship between the change in kidney volume and pretransplant kidney volume/pretransplant recipient's weight.

Implant and post-transplant glomerular size

Implant glomerular size showed that the diameter was 165.3 ± 15.1 μm and the area 20,737.1 ± 3230.6 μm^2 (Table 2). These values did not show a correlation with donor age, height, and weight. The glomerular size varied between donor genders, but there were no significant differences in both parameters. Reduction in glomerular size was observed in the diameter in 41 cases (87.2%) and in the area in 42 case (89.4%). Glomerular size at 1 year post-transplant showed statistical comprised a diameter of 150.6 ± 11.4 μm and area of 17,428.3 ± 2577.9 μm^2, statistically significant in comparison with implant glomerular size (both $P < 0.001$). Percentage changes were −8.3% (IQR −14.9 to −3.7) in diameter and −14.9% (IQR −27.2 to −6.1) in area. Reduced glomerular size was detected despite donor gender, and these sexual gaps in glomerular size became narrower at 1 year after transplantation. Both glomerular size parameters at implant and 1 year post-transplant did not present correlations for the Δk-vol from pretransplant to 1 year post-transplant (Table 3). The Δdiameter and Δarea in glomerular size also showed no associations with Δk-vol.

Table 2. Glomerular size in implant and 1-year post-transplant biopsies.

	Diameter (μm)	Area (μm^2)
Implant biopsy		
Total	165.3 ± 15.1[a]	20737.1 ± 3230.6[b]
Donor (male)	168.3 ± 18.5[c]	21616.7 ± 4176.4[d]
Donor (female)	163.5 ± 12.7[e]	20191.1 ± 2397.9[f]
Donor age	r = 0.212/P = 0.150	r = 0.045/P = 0.336
Donor height	r = 0.215/P = 0.146	r = 0.225/P = 0.128
Donor weight	r = 0.577/P = 0.212	r = 0.241/P = 0.103
One-year post-transplant biopsy		
Total	150.6 ± 11.4[a]	17428.3 ± 2577.9[b]
Donor (male)	151.7 ± 13.6[c]	17942.0 ± 3216.6[d]
Donor (female)	150.0 ± 10.0[e]	17109.5 ± 2088.3[f]

[a–f]Significant at $P < 0.001$.

Table 3. Correlation analysis of differences in the change of kidney volume and glomerular size.

	Δk-vol (pre- to post-Tx)	
	r	P
Implant		
Diameter (μm)	0.073	0.627
Area (μm^2)	0.031	0.836
One-year post-Tx		
Diameter (μm)	0.053	0.724
Area (μm^2)	0.057	0.704
Change in glomerular size (implant to 1 year post-Tx)		
ΔDiameter	0.136	0.364
ΔArea	0.091	0.544

k-vol, kidney volume; Tx, transplant.

Post-transplant graft function

The overall post-transplant eGFR (ml/min/1.73 m^2) at 1 month, 3 months, and 1 year was 108.0 ± 36.3, 93.3 ± 37.7, and 78.6 ± 21.7, respectively (Fig. 2). Significant reductions of eGFR were evident at each period (all $P < 0.001$). ΔeGFR was −12.8% (IQR −24.9 to −4.6) from 1 to 3 months post-transplant, −11.1% (IQR −24.7 to −0.1) from 3 months to 1 year post-transplant, and −25.6% (IQR −34.1 to −10.8) from 1 month to 1 year post-transplant. eGFR at 1 year post-transplant had weak positive correlation with the Δk-vol (Table 4). These ΔeGFR values (1–3 months, 3 months to 1 year, and 1 month to 1 year) were not related to the Δk-vol from pretransplant to 1 year post-transplant.

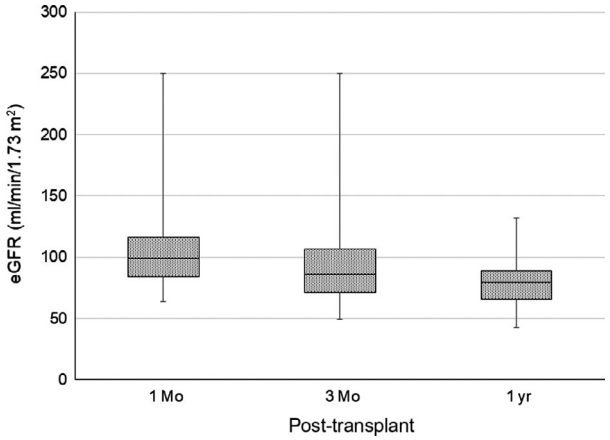

Figure 2 Post-transplant eGFR within 1 year.

Table 4. Correlation analysis of differences in the change of kidney volume and graft function.

	Δk-vol (pre- to post-Tx)	
	r	P
eGFR (ml/min/1.73 m^2)		
1 month post-Tx	0.246	0.096
3 months post-Tx	0.248	0.093
1 year post-Tx	0.290	0.047
ΔeGFR		
1–3 months	0.060	0.672
3 months to 1 year	0.001	0.993
1 months to 1 year	0.033	0.818

eGFR, estimated glomerular filtration rate; k-vol, kidney volume; Tx, transplant.

Factors affecting the change in kidney volume

Factors affecting the Δk-vol estimated by simple linear regression analysis and multiple regression analysis include donor- and recipient-associated factors (Table 5). Simple linear regression analysis suggested these to be pretransplant k-vol (increasing by 10 ml, ml/10 ml k-vol), pretransplant R-aCav volume (increasing by 200 ml, ml/200 ml cavity volume), donor gender (male), transplant approach (extraperitoneal), percentage change in recipient's height per year (increasing by 5%, ml/5% of height gain), and percentage change in recipient's weight per year (increasing by 5%, ml/5% of weight gain). Significant association with Δk-vol was demonstrated in pretransplant R-aCav volume and percentage change in recipient's weight per year. Furthermore, multivariable analysis also showed that pretransplant R-aCav volume (β = 0.029; SE = 0.009;

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Table 5. Analysis of the factors of the change in kidney volume using simple linear regression and multiple regression analysis.

	Univariable analysis			Multivariable analysis		
	β	SE	*P*	β	SE	*P*
Pre-Tx k-vol (increasing by 10 ml)	−0.017	0.009	0.068	−0.023	0.009	0.011
Pre-Tx R-aCav (increasing by 200 ml)	0.026	0.009	0.007	0.029	0.009	0.004
Donor gender (male)	−0.083	0.045	0.072	−0.021	0.044	0.627
Tx approach (extraperitoneal)	0.076	0.044	0.095	0.039	0.040	0.346
Percentage change in recipient's height per year (increasing by 5%)	0.001	0.025	0.967	−0.005	0.025	0.853
Percentage change in recipient's weight per year (increasing by 5%)	0.021	0.007	0.002	0.020	0.006	0.002

k-vol, kidney volume; R-aCav, recipient's abdominal cavity volume; SE, standard error; Tx, transplant; β, partial regression coefficient.

$P = 0.004$) and percentage change in recipient's weight per year ($\beta = 0.020$; SE = 0.006; $P = 0.002$) were factors affecting the change in k-vol after transplantation.

Discussion

To our knowledge, this is the first study to report on the change in the kidney volume and glomerular size from pre- to post-transplant in transplantation of an adult-size kidney to small pediatric recipients. This study revealed the post-transplant adult-size kidney in small pediatric recipients became smaller than the pretransplant kidney in terms of macro- and microstructure. The post-transplant reduction in k-vol was influenced by pretransplant physique and post-transplant weight gain. However, the Δk-vol did not reflect the fluctuation of short-term renal function.

In small pediatric recipients, volume reduction in adult-size kidneys may be necessary for volumetric adaptation to adult-size kidneys. Currently, there is sparse literature concerning the change in adult-size k-vol in pediatric transplants. In adult transplants using an adult kidney, the graft became expanded by 27.3% through 1 year after transplantation [6]. By contrast, adult-size kidneys in pediatric recipients shrunk by 26–31% because of inadequate renal blood flow [7,8]. In our study, the post-transplant k-vol was reduced by 17.2%, but only seven cases had increased k-vol 1 year later (increase rate of 0.5–25.7%). The pediatric abdominal space is narrow and limited for an adult-size kidney. Narrow abdominal space results in interference with expansion of the graft after reperfusion, whereby RACS occurs as a result of compression [3,4]. Therefore, it is difficult to preserve original pretransplant k-vol because of this extrinsic background factor in size mismatch. Primary poor arterial supply based on low circulating blood volume in a small physique and/or secondary poor arterial supply because of RACS are intrinsic factors. Moreover, 14.9% of our cases exhibited increased k-vol; we speculate that intrarenal blood congestion due to suboptimal venous drainage following size mismatch might constitute another intrinsic factor that regulates k-vol. This study demonstrated that pretransplant R-aCav volume and post-transplant weight gain were crucial in preventing reduction of k-vol, possibly indicating that a large R-aCav creates room for the graft while continuous growth increases circulating blood volume and renal blood flow. In contrast, clinical parameters such as warm ischemic time, cold ischemic time, secondary warm ischemic time, clinical acute rejection, and subclinical acute rejection did not affect the change in k-vol (data not shown). Therefore, the extrinsic and intrinsic factors are complex and involved in regulating the k-vol in small pediatric patients with an adult-size transplanted kidney.

Although the adult-size kidney requires sufficient blood flow to maintain the organ's activity and express whole renal function, there is a discrepancy in blood volume between the limited blood supply in small recipients and the blood flow demanded by large kidneys. Hypoperfusion of adult-size kidneys has been observed in small pediatric transplant recipients weighing less than 16 kg [7]. Aortic blood flow in these recipients increased by over twofold after transplantation. However, the post-transplant renal artery blood flow with reduced k-vol did not reach prenephrectomy in situ donor renal artery blood flow. The main renal artery should be anastomosed to the aorta to maintain adequate blood flow in recipients weighing less than 20 kg [11]. It is reasonable to prevent ischemic damage by using anastomosis between the main renal artery and the greater artery in small recipients. In our study, the aorta was the first anastomotic site of the main renal

artery in 43 cases (91.5%); the common iliac artery was used in the remaining four cases.

Our study showed that the glomerular area at 1 year post-transplant was reduced, and that this value was similar to that in adolescents in the normal pediatric population [12]. Shrinking glomeruli act as part of their adaptation to the child organism. In adult transplants, pathological estimation of glomerular lesions showed enlarged glomeruli, possibly because the single kidney suffered hyperfiltration to enable adaptation [13]. Enlarged glomeruli with excessive filtration can lead to nephron exhaustion and subsequent graft loss. In our study, enlarged glomerular size was uncommon and most glomeruli were reduced in size. The increasing percentage change in diameter was 0.9–9.5% in six cases (12.8%), and the percentage change in area was 4.2–22.4% in five cases (10.6%).

Although shrunken kidney and reduced glomerular size show intrarenal hypofiltration, reduced or normalized glomerular size of the adult-size kidney in small pediatric recipients would be expected to lead to long-term nephron survival rather than hyperfiltration if there was no glomerular sclerosis caused by ischemia. By contrast, graft ischemia associated with donor-recipient size discrepancy leads to subsequent reversible or irreversible ischemic damage [14]. The discrepancy causes ischemic damage including acute tubular necrosis, which is related to graft survival [15], and also adds risk factors for chronic nonimmunological histological injury, including glomerular shrinkage in an adult-size kidney transplanted into small children [16]. In addition, Gholami et al. revealed that smaller recipients (BSA <0.75 m^2) had higher resistive index in adult-size kidneys [8], and suggested that this phenomenon may be caused by efferent arteriolar vasoconstriction through the renin–angiotensin–aldosterone system to accommodate the discrepancy.

An adult-size kidney affords nephron mass for pediatric recipients and has better renal function because of a relatively higher nephron mass. The BSA ratio between donor and recipient influenced graft survival in terms of nephron dosing [17]. By contrast, it did not increase renal function and reach a plateau of eGFR according to body size when extra nephrons were added [18]. Functional adaptation to the size mismatch in transplantation of adult-size kidney to a child has been demonstrated, whereby the GFR was gradually reduced until 1 year post-transplant and became stable thereafter [7,19,20]. A similar reduction of eGFR in the early post-transplant period was observed in our study. Adult-size grafts may adapt to pediatric recipients during the first months after transplantation, but the graft function does not parallel the growth [21]. The mechanism underlying this functional adaptation is still unclear, although the lower blood volume of the small recipient results in renal hypoperfusion and low eGFR. Kidneys can respond to changes in the functional demand of pediatric patients. This may result in lower blood pressure, leading to glomerular hypofiltration in the transplanted kidneys to counterbalance the excessive renal function in a small physique. Although there was suboptimal renal perfusion compared with pretransplant renal perfusion even if recipients received supplemental fluid perioperatively, fluid load for intravascular volume expansion improved post-transplant GFR in infants [22]. Long-term maintenance of optimal intravascular volume is necessary to preserve the original k-vol, and it is important to encourage fluid intake after transplantation. In our center, fluid intake of more than 1000 ml/day is routinely recommended after transplantation in small pediatric recipients. Although graft volumetry forecasts post-transplant graft function in adult transplants with an adult kidney [23], there was a poor relationship between pretransplant k-vol and short-term graft function in our study. Compared with adult recipients, eGFR in pediatric recipients was influenced by their increasing height and the adult-size kidney became shrunken [6,10]. Adult-size grafts became smaller while pediatric patients continued to grow, with the initial size mismatch seeming to be resolved as time advanced. Considering these complicated situations, graft volumetry in pediatric transplants with an adult-size kidney would not be feasible as a predictor of graft function.

The limitations of this study were the short-term observation and the small number of cases. Pathological specimens and counts of glomeruli were limited only to needle biopsy samples. As a result, there is a possibility of histological over- or underestimation of glomerular size. Increasing renal blood flow would be expected via growth, with the intrarenal hypoperfusion seeming to be resolved. It is unclear whether the initial volume loss after transplantation has disadvantages for future graft outcomes in small pediatric recipients. More longitudinal histological evaluations need to reveal how to minimize chronic hypoperfusion as a result of donor–recipient size discrepancy. An important issue is whether the smaller graft could support their growth until maturity and whether these grafts could regain their own k-vol and glomerular size. Further study needs to reveal the graft volume and patient growth after long-term careful observation including pathological estimations.

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In conclusion, an adult-size kidney can be accommodated by small pediatric recipients weighing less than 15 kg, accompanied by reduction in k-vol at 1 year after transplantation. These grafts seem to represent compensatory atrophy with relative ischemia, and pre-transplant physique and post-transplant somatic growth were complex aspects involved in the post-transplant k-vol. At the very least, however, the reduced k-vol had no negative impact on the short-term graft function.

Authorship

MM and TM: participated in research design; participated in the writing of the paper; participated in the performance of the research; participated in data analysis. YH: participated in research design; participated in the writing of the paper; participated in the performance of the research; participated in data analysis; drafting the work or revising it critically for important intellectual content. YT, JH, MK, HO, TY, KS, YA, KS, YI and TK: participated in research design; participated in the performance of the research. NS, TM, KS, KS, SS: drafting the work or revising it critically for important intellectual content; final approval of the version to be published.

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Conflicts of interest

The authors have declared no conflicts of interest.

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