Original Article

Successful single kidney transplantation from pediatric donors less than or equal to 10 kg to adult recipient: a retrospective cohort study

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Background: Kidneys from very small pediatric donors (≤10 kg) are underutilized. Compared to en bloc kidney transplantation (EBKT), single kidney transplantation (SKT) can maximize donor resources. However, it remains unknown whether it's appropriate to perform SKTs from donors weighing ≤10 kg.

Methods: A total of 35 adult recipients undergoing kidney transplantation from donors weighing ≤10 kg at our center from December 2014 to December 2019 were included and grouped into SKT group (n=20) and EBKT group (n=15). Transplant outcomes were retrospectively analyzed and compared between 2 groups.

Results: The 1-year and 3-year death-censored graft survival in SKT group was 95%, it is not significantly higher than that in EBKT group (80%, log-rank test, P=0.38). Significant improvement in estimated glomerular filtration rate (eGFR) was noted in both groups, despite eGFR at 1 year was lower in the SKT group (P<0.01). Proteinuria was common in both groups but subsided gradually during the follow-up time. Complication rates were similar between 2 groups with no vascular thrombosis in the SKT group.

Conclusions: In conclusion, SKTs from donors weighing ≤10 kg to adult recipients achieves comparable outcomes with EBKTs, which provides evidence to support performing SKTs from donors weighing ≤10 kg in certain donor and recipient scenarios.

Keywords: Single kidney transplantations; pediatric donors; adult recipients

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Introduction

Kidney transplantation remains the better choice of treatment for many patients with end-stage renal disease (ESRD) compared to dialysis since it can provide extending survival and better quality of life for patients (1,2). However, there is a great disparity between the waitlist patients and available donor kidneys, which motivates the transplant community to find a new strategy to expand the donor pool. Kidneys from pediatric donors are considered as suitable organ sources to alleviate the current dilemma and nowadays pediatric donors have been increasingly used for

kidney transplantation (3). However, utilization of pediatric donor kidneys, especially kidneys from small pediatric donors, has provoked concerns over increased risks for perioperative complications and hyperfiltration injury. En bloc kidney transplantation (EBKT) has been performed to overcome these concerns by doubling the nephron mass and similar graft survival were observed in comparison with adult deceased donor kidneys or even living donor kidneys (3-8). Moreover, the lower incidence of thrombosis in EBKTs, as well as lower incidence of stenosis and turbulence can be attributed to the larger vascular caliber in EBKT. However, some argue that despite being small in size, pediatric donor kidneys have the ability to improve their function over time and maintain promising estimated glomerular filtration rate (eGFR) over the long term (9,10). What's more, by carefully choosing the proper recipients and using donor aortic patch to enlarge anastomosis, single kidney transplantation could be a feasible choice. Therefore, single kidney transplantation (SKT) using small pediatric donor kidney is now reconsidered and becoming more and more popular since it can maximize the numbers of recipients.

However, the current situation has posed a challenge for transplant surgeons: when to split the small pediatric *en bloc* kidneys for SKTs in two adult recipients without compromising graft outcomes. There is an inverse relationship between donor body weight and organ discard rate within pediatric donors (11). Donors with lower body weight are less likely to be used and it leads to 40.3% of kidneys from donors weighing less than 10 kg were discarded (11). But these donors do serve as an important potential kidney resources and now emerging studies show comparable outcomes by using such small donor kidneys when compared to larger donor kidneys either in EBKTs (5,12) or SKTs (10,13). It remains unknown whether it is safe enough to split the pediatric *en bloc* kidneys into two single kidneys even from donors ≤10 kg. In our clinical practice, we have performed many cases of EBKTs and SKTs in adult recipients using small kidneys from pediatric donors ≤10 kg. In this study, we chose 10 kg as cutoff point of lower weight limit, compared the outcomes of SKTs and EBKTs in adult recipients using small pediatric kidneys and investigated the hypothesis that kidney graft outcomes in SKTs could be equivalent to EBKTs from donors ≤10 kg. We present the following article in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/tp-21-23).

Methods

Patient population

All adult (≥18 years old) patients who received pediatric kidney grafts from donors whose body weight (BW) ≤10 kg at the First Affiliated Hospital of Sun Yat-sen University between December 2014 to December 2019 were retrospectively analyzed. A total of 35 cases were included and they were divided into two groups based on transplant procedure, the SKT group in which patients received single kidney graft, and the EBKT group containing patients receiving en bloc kidney grafts. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the institutional ethics committee of the First Affiliated Hospital of Sun Yat-sen University {No. [2016]086}. This study is consistent with the principles of the declaration of Istanbul as outlined in the "Declaration of Istanbul on Organ Trafficking and Transplant Tourism." As the study design was retrospective and observational, informed consent from the study subjects was not required.

Allocation principle

In clinical scenarios, we follow a general allocation principle to choose SKTs or a EBKTs for a particular recipient, and elaborated as follows: (I) for donor weighing ≤5 kg, EBKT was chosen as surgical procedure; (II) for donor weighing 5–10 kg, the allocation is mainly based on the donor/recipient weight ratio, (III) female recipient get priority to perform kidney transplantation from donor weighing ≤10 kg. And the general allocation procedure was made to ensure that this part of the donor kidney would not be discarded and be fully utilized.

Surgical technique and perioperative care

Pediatric *en bloc* kidney transplant or single kidney transplant were performed using previously described techniques (14). To be more specific, for EBKTs, en bloc kidneys were recovered with the aorta, vena cava and bilateral ureters. Back table preparation involved careful dissection of the perinephric fat and closure of the infrarenal section of the donor abdominal aorta (AA) and inferior vena cava (IVC). The proximal ends of donor AA and IVC were then anastomosed to the recipient's external iliac artery and vein in an end-to-side manner, respectively,

using a running 7-0 Prolene suture. The en bloc graft was placed properly to prevent vessel distortion in the iliac fossa. In our procedure, the en bloc graft were placed straddling the iliac vessels. The left kidney was in the right iliac fossa, while the right kidney was in the space between the bladder and right pelvic wall. This procedure allows more space to place en bloc grafts with reduced request for the length of anastomosis vessels (15). For SKTs, back table preparation involved meticulous split of the *en bloc* kidney graft and separate dissection of the perinephric fat. Notably, tissue around the renal vessels were kept undissected and donor aortic (Carrel) patch was prepared for anastomose. To create a wide artery anastomosis, the abdominal aortic patch is trimmed in the back table preparation. Furthermore, the renal vein can be extended with the inferior vena cava and the inferior vena cava can be obliquely cut to form a wide venous anastomosis. The single kidney artery with Carrel patch and vein were anastomosed to the recipient's external iliac artery and vein in an end-to-side manner, respectively, using a running 7-0 Prolene suture. Ureteroneocystostomy was performed by the LichGregoir technique with placement of a ureteral stent both in EBKTs and SKTs.

To prevent vasospasm, papaverine (30 mg in 10 mL of saline) was directly injected into donor AA or renal artery before blood reperfusion and was continuously pumped by 2 mL/h (60 mg in 50 mL of saline) for three days after transplantation. And all the recipients received low molecular weight heparin (LWMH, 50–100 IU/kg/d) for 1–5 days for anticoagulation and minor adjustments of the dosage was made based on post-operative drainage volume around the allograft and graft ultrasound examination. The systolic blood pressure of the recipients was maintained below 140 mmHg.

Immunosuppression

For induction therapy, patients obtained either thymoglobulin or basiliximab. Basiliximab was administered at a dose of 20 mg on day 0 and day 4. Anti-thymocyte globulin (Rabbit) was administered at a dose of 50 mg/d from day 0 to day 2. For maintenance immunosuppression, patients received tacrolimus or cyclosporine, combined with mycophenolic acid and steroids. Tacrolimus was administered at a dose of 0.1–0.15 mg/kg/d from day 1, with a targeted trough level of 8–10 μg/L initially and 6–8 μg/L after 3 months. Cyclosporine was administered from day 1, with a targeted trough level of 150–200 ng/mL initially and 130–180 ng/mL after 3 months. Mycophenolate mofetil was initiated at a dose of 1.0–2.0 g/d (Mycophenolate mofetil) or 1,080–1,440 mg/d (Enteric-coated mycophenolate sodium) and then adjusted the dosage based on recipient's white blood cell count or gastrointestinal disorders. Methylprednisolone was administered intravenously at a dose of 500 mg/d from day 0 to day 2, followed by an oral dose of prednisone at 30 mg/d, and then it was gradually tapered down to a maintenance dose of 2.5–10 mg/d.

Data collection

All data including perioperative care and postoperative follow-up till April 2020 was collected through retrospective chart review. Donor and recipient baseline characteristics of the SKTs and EBKTs groups were collected and compared. The estimated glomerular filtration rate (eGFR) was calculated using the Chinese-modified Modification of Diet in Renal Disease (MDRD) equation for kidney graft function assessment (16). Graft ultrasound examination was consecutively implemented during follow-up, and renal length was analyzed to demonstrate graft growth. Posttransplant outcomes including graft and patient survival, kidney graft function, development of proteinuria, and complications [primary nonfunction (PNF), delayed graft function (DGF), vascular thrombosis, ureteral complications, rejection, infection and recurrence of primary diseases] were compared between the 2 groups. PNF was defined as renal grafts that never recover renal function caused by nonimmunological cause (17). DGF was defined as the need for at least one session of dialysis during the first week posttransplant (18,19).

Statistical analysis

All metric data are presented as median and range, while categorical variables were reported as frequency and percentage. Categorical variables were analyzed by Chi-square or Fisher's exact test, whereas continuous variables between the two groups were compared by Mann-Whitney rank sum test. Graft and patient survival were calculated according to Kaplan-Meier method and compared between the 2 groups with log-rank (Mantel-Cox) test. A P value of <0.05 was considered statistically significant. All statistical analysis was conducted with SPSS version 26 (SPSS Inc., Chicago, IL, USA) and Graphpad Prism version 8.0 for Macbook (GraphPad Software, La Jolla, CA, USA).

Table 1 Donor demographics

Donor demographics	SKT	EBKT	P value
Donor number	14	15	–
Age, median (range), months	17 (6.5–29.0)	5 (0.1–22.0)	<0.001
Male, n (%)	6 (42.9)	10 (66.7)	0.18
Body weight, median (range), kg	9.5 (6.0–10.0)	7.5 (2.1–10.0)	0.005
Cause of death			0.13
Trauma	3	3	
Hypoxic ischemic encephalopathy	2	3	
Cerebral hemorrhage	2	3	
CNS infection	0	2	
CNS tumor	0	1	
Congenital diseases	0	2	
Others	7	1	
Donor type			0.439
DBD, n (%)	7 (50.0)	6 (40.0)	
DCD, n (%)	6 (42.9)	9 (60.0)	
DBCD, n (%)	1 (7.1)	0 (0.0)	
WIT, median (range), min	1.5 (0.0–15.0)	5.0 (0.0–60.0)	0.107
CIT, median (range), h	10.0 (4.0–16.0)	11.0 (6.0–23.0)	0.133

CIT, cold ischemia time; CNS, central nervous system; DBD, donation after brain death; DBCD, donation after brain and cardiac death; DCD, donation after cardiac death; EBKT, en bloc kidney transplantation group; SD, standard deviation; SKT, single kidney transplantation group; WIT, warm ischemia time.

Results

Demographic characteristics

A total of 35 patients who received kidney grafts from donors weighing less than or equal to 10 kg were involved in this study cohort and they were divided into SKT (n=20) and EBKT (n=15) groups. Donors and recipients' characteristics were summarized in *Tables 1*,*2*, respectively. In comparison with the donors in EBKT group, the donors in SKT group were older and heavier (median age, 17 *vs.* 5 months, P<0.01, median weight, 9.5 *vs.* 7.5 kg, P<0.01, *Figure 1A*,*B*). Trauma (n=2), hypoxic ischemic encephalopathy (n=2) and intracerebral hemorrhage (n=2) accounted for 50% of the cause of donor death in SKT group while central nervous system infection (n=2) and congenital heart diseases (n=2) were also common cause of donor death in EBKT group. These two groups shared similar percentages of donation after brain death (DBD), donation after brain and cardiac death (DBCD) and donation after cardiac death (DCD) in this study cohort (50%, 5%, and 45% in the SKT group *vs.* 40%, 0%, and 60% in the EBKT group, P>0.05). The warm ischemia time of kidneys in the SKT group was slightly shorter than that in the EBKT group, but with no significant statistic differences (median time, 1.5 *vs.* 5.0 min, P=0.107). And the cold ischemia time of kidneys in the SKT group was similar to that in the EBKT group (median time, 10 *vs.* 11 hours, P=0.133).

The SKT and EBKT groups shared similar recipient characteristics (*Table 2*). All recipients received their primary kidney grafts except for one recipient in the SKT group received his secondary kidney transplantation. No significant differences were observed between these two groups when compared in terms of recipient age, gender, body weight, the time and way of dialysis, induction therapy or maintenance immunosuppressive regimens. But the

Table 2 Recipient demographics

Recipient demographics	SKT (N=20)	EBKT (N=15)	P value
Age, median (range), years	41.5 [21–64]	38 [21–54]	0.333
Female, n (%)	16 (80.0)	8 (53.3)	0.189
Body weight, median (range), kg	46.5 (35.5–61.4)	49 [35–81]	0.494
Pretransplant dialysis, n (%)			0.276
Hemodialysis	14 (70.0)	13 (86.7)	
Peritoneal dialysis	3 (15.0)	2 (13.3)	
Pre-emptive transplant	3 (15.0)	0	
Dialysis time, median (range), months	13 (0–128)	22 (3–53)	0.803
Retransplant, n	1	0	1
Induction therapy, n (%)			0.794
Lymphocyte depleting	19 (95.0)	13 (86.7)	
Basiliximab	1 (5.0)	2 (13.3)	
Maintenance regimen, n (%)			1
Tac + MPA + Pred	19 (95.0)	15 (100.0)	
CsA + MPA + Pred	1 (5.0)	0	
Follow-up time, median (range), months	17 (0–60)	13 (0–61)	0.815

CsA, cyclosporine; EBKT, en bloc kidney transplantation group; MMF, mycophenolate mofetil; Pred, prednisolone; SKT, single kidney transplantation group; Tac, tacrolimus.

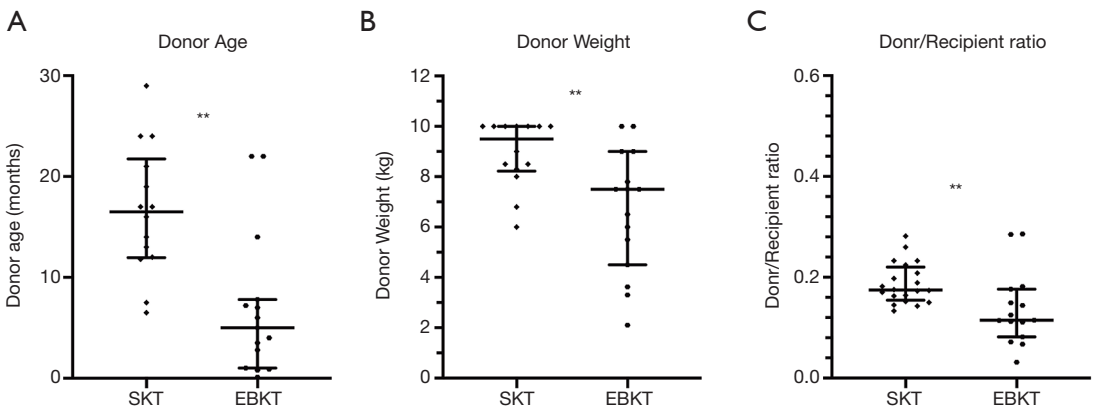

Figure 1 Demographic disparity between SKT and EBKT group. (A) Comparison of donor age in the SKT group and EBKT group; (B) comparison of donor weight in the SKT group and EBKT group; (C) comparisons of donor/recipient weight ratio in the SKT group and EBKT group. **P<0.01, noted statistically significance. EBKT, en bloc kidney transplantation; SKT, single kidney transplantation.

donor/recipient body weight ratio was higher in the SKT group (median 0.17 *vs.* 0.11, P<0.01, *Figure 1C*) and this was caused by the allocation procedure of SKT/EBKT based on donor/recipient weight ratio that we mentioned above. The median follow-up time was 21 and 16 months in the SKT and EBKT group, respectively.

Patient and graft survival

During the follow-up period, a total of 8 kidney grafts

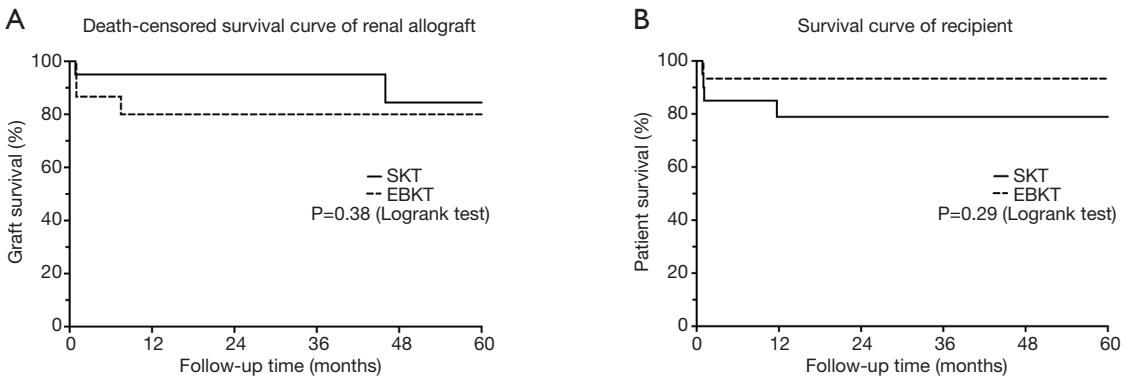

Figure 2 Patient and graft survival. (A) Death-censored graft survival in the SKT group and EBKT group, no significant difference between two groups (P=0.38); (B) patient survival in the SKT group and EBKT group, no significant difference between two groups (P=0.29). EBKT, en bloc kidney transplantation; SKT, single kidney transplantation.

failed (5 in the SKT group and 3 in the EBKT group). Three patients died with functioning graft caused by severe pneumonia in the SKT group. The main cause leading to graft loss in the SKT group was patient death with a functioning graft (n=3, 60%) while that in the EBKT group was graft vascular thrombosis (n=2, 67%). In addition, all graft losses in the EBKT group occurred within 1-year posttransplant, while one graft failed caused by chronic rejection was observed 3 years posttransplant in the SKT group. Therefore, 1-year death-censored graft survival (DCGS) was 95% and 80% in the SKT group and the EBKT group, respectively, and so as the 3-year DCGS. The 5-year DCGS decreased to 85% in the SKT group and maintained as 80% in the EBKT group. No significant differences were observed in term of DCGS (log rank test, P=0.38, *Figure 2A*). Four patients died in the SKT group within 1-year posttransplant, among whom the primary cause was severe pneumonia (n=3, 75%). The remaining one died secondary to coagulation disorder and severe bleeding. That led to a relatively low 1-year patient survival of 85% and it maintained till 3- and 5-year posttransplant. One patient died in the EBKT group because of acute myocardial infarction and 1-, 3- and 5-year patient survival maintained as 95%. No significant differences were observed in term of patient survival (log rank test, P=0.29, *Figure 2B*).

Renal growth evaluation and graft function

Most recipients in both groups obtained recovery of renal function early after transplantation. Notably, renal allograft function constantly improved in both groups as shown in *Figure 3A*. At 1-year posttransplant, the median eGFR in the SKT group was lower than that in the EBKT group (median eGFR 77.53 *vs.* 108.52 mL/min/1.73 m^2, P<0.01), but it continued to increase till 2 year and no significant difference were observed at that time between these two groups (*Figure 3A*).

Over 30% patients in both groups presented significant proteinuria (defined as urinary protein test + to +++) in the initial postoperative period. But the percentage of recipients with proteinuria in both groups presented obvious decreasing tendency and most of the proteinuria subsided within 2-year posttransplant (*Figure 3B*).

Kidney grafts also gained satisfactory growth posttransplant (*Figure 4*). At the first week posttransplant, grafts from the SKT group were significantly bigger than the grafts from the EBKT group (median length 7.5 *vs.* 5.6 cm, P<0.01, *Figure 4*), partly due to the relatively heavier donors from the SKT group. Even though graft size in both groups did not meet the standard adult kidneys size, the graft size difference was abrogated by the second week posttransplant and the grafts of all patients grew at similar rates with continuous growing tendency.

Posttransplant complications

Posttransplant complications in two groups were summarized in *Table 3*. DGF was more common in the SKT group than in the EBKT group [3/20 (15%) *vs.* 2/15 (13.3%)]. All the three DGF patients in the SKT group regained normal kidney function but one of them ended up with graft loss due to severe kidney graft bleeding at 20 days posttransplant. One DGF patient in the EBKT group recovered to normal

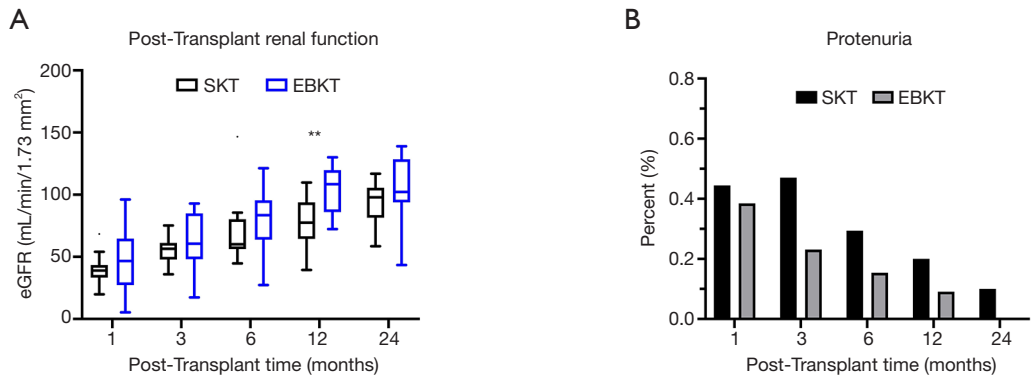

Figure 3 Renal allograft function after kidney transplantation. (A) Post-transplant eGFR of recipients in the SKT group and EBKT group. The eGFR steadily increased in both groups for 2 years post-transplant and there were no significant differences between two groups except for a little higher eGFR in the EBKT group was observed in 1-year post-transplant (P<0.01). (B) Percent of patients with proteinuria declined rapidly in both groups over 2 years post-transplant. There were no significant differences between two groups. **P<0.01, noted statistically significance. eGFR, estimated glomerular filtration rate; EBKT, en bloc kidney transplantation; SKT, single kidney transplantation.

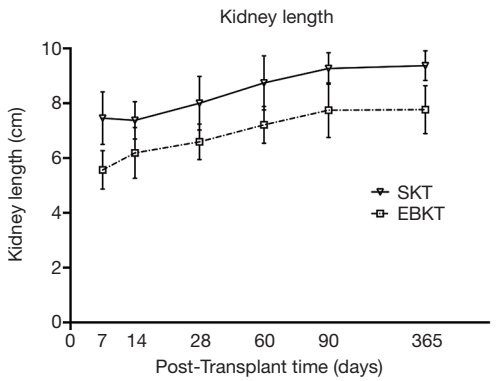

Figure 4 The growth of pediatric renal allografts after transplantation. Renal graft length in the SKT group and EBKT group measured by consecutively implemented ultrasonography in the first-year post-transplant. EBKT, en bloc kidney transplantation; SKT, single kidney transplantation.

kidney function while the other one lost his graft due to thrombosis at 3 days posttransplant. Three of the five patients died of pneumonia and the other two recovered after antibiotic therapy. Only one patient in the EBKT group developed pneumonia and recovered after treatment. One cases of biopsy-proven acute rejection in the SKT group could recover to normal kidney function after intensive anti-rejection therapy while the other one developed to chronic rejection that led to late graft loss. No vascular thrombosis occurred in the SKT group, but two happened in the EBKT group and all ended up with graft losses. But one patient in the SKT group developed artery stenosis and was resolved by stent implantation. Regarding ureteral complication, one patient in the EBKT group happened to persistent urinary leak and finally lost the graft. And his kidney function remained good during the follow-up period. One recurrent focal segmental glomerular sclerosis (FSGS) was observed in the SKT group but no graft loss happened after intensive treatment.

Discussion

The great disparity between the waiting list of patients with ESRD and scarce resource of deceased donor kidneys still exists. Great efforts have been made to expand the deceased donor pool by utilizing small pediatric donor kidneys.

However, no criteria have been established to allocate the small pediatric donor kidneys. Traditionally, small pediatric donor kidneys tended to be used in EBKTs because of the concern whether a small pediatric kidney graft is sufficient enough for adequate renal function in adult recipients (20,21). But SKTs would be the better choice if satisfactory clinical outcomes can be achieved since they could effectively utilize the limited deceased donor sources. Emerging reports showed transplantation of a single kidney from pediatric donors to an adult recipient could gain similar outcomes in comparison with *en bloc* pediatric kidney transplantation and significant attempts had been made to explore the lower limit of donor weight for SKTs (10,13,22). Actually, there seems to be a consensus that

Table 3 Complications in SKT and EBKT groups

Complications	SKT (N=20)	EBKT (N=15)	P value
Primary nonfunction, n (%)	0	0	–
Delayed graft function, n (%)	3 (15%)	2 (13.3%)	0.889
Pulmonary infection, n (%)	5 (25%)	1 (6.7%)	0.154
Urinary infection, n (%)	1 (5%)	1 (6.7%)	0.681
Biopsy-Proven Acute Rejection, n (%)	2 (10%)	0	0.207
Vascular thrombosis, n (%)	0	2 (13.3%)	–
Artery stenosis	1	0	–
Ureteral stenosis, n (%)	1 (5%)	0	–
Urinary leak, n (%)	0	1 (6.7%)	–
Recurrence of primary disease	1 (5%)	0	–
One-year mortality	4 (25%)	1 (6.6%)	0.38
Cause of death			–
Severe pneumonia	3	0	
Hypoxic ischemic encephalopathy	1	0	
Acute myocardial infarction	0	1	

SKTs can be safely performed if the donor weighs >15 kg in Western society (23). But SKTs performed in donor weighs ≤15 kg or ages ≤3 years have been proven to be a possible choice in China (24). In our center, many cases of SKTs in adult recipients using small kidneys from pediatric donors ≤10 kg have been performed. And as mentioned above, based on actual clinical scenarios, we put forward a general donor and recipient criteria for selecting SKTs as surgical procedure. In this study, we demonstrated that in certain donor and recipient scenarios, SKTs could attain satisfactory short-medium term graft function and graft survival even when kidneys were from donors weighing ≤10 kg. Such results may promote the transplant community to split the kidneys from donors ≤10 kg confidently to perform SKTs in experienced transplant centers.

Development of SKTs using kidneys from donors weighing ≤10 kg can not only make the best use of those potentially discarded donor kidneys but also maximize the recipients' benefits. A published report analyzing the Scientific Registry of Transplant Recipient (SRTR) data showed that higher kidney discard rate was associated with low donor weight. In particular for donor weight ≤10 kg, the discarded kidneys including non-recovered and recovered but not transplanted kidneys accounted for 54.2% among all the deceased donors. Moreover, the percentage of SKTs was only about 16% to 24% (25). Another analysis of SRTR data claimed that small kidneys from pediatric donors weighing >10 kg could be considered for SKTs, whereas kidneys from donors weighing ≤10 kg should all be used for EBKTs (26). However, several studies had involved cases using kidney from donors weighing ≤10 kg for SKTs and showed relatively good outcomes. For example, Mohanka *et al.* (27) reported SKTs from donors weighing ≤15 kg (n=14, including 3 cases of donors weight ≤10 kg) showed short-term outcomes with minimal complications; Fayek *et al.* (28) showed us similar short term (3 months posttransplant) graft function when comparing 4 cases SKTs with 20 cases EBKTs using kidneys from donors weighing <10 kg. As for our study, though all kidneys were from donors weighing ≤10 kg, excellent posttransplant graft outcomes were achieved during the follow-up time in the SKT group and no significant differences were observed when compared to the EBKT group. Impressively, the 1-year and 3-year DCGS in the SKT group was even higher than the EBKT group (95% *vs.* 80%). It is of note three patients died of pulmonary infection with renal allograft function. This might be associated with relatively weakened immunity since they were female with low body weight (24), instead of SKT technique itself. Therefore, our study results provided evidence

to support effectiveness and safety of SKTs from very low body weight (≤10 kg) pediatric donors in certain donor and recipient scenarios.

There have been many concerns regarding the use of small pediatric kidneys and choice of performing SKTs. Among them, inadequate renal mass, increased risk of technical complications and hyperfiltration injury are the most commonly cited.

The first major concern is inadequate nephron mass regarding the use of small pediatric kidneys as SKTs. The development of the nephrons is thought to be completed at 36 weeks of gestation (29) and a single kidney at birth contains an estimated 1.0 million nephrons that are sufficient for an adult (30). However, many centers are discouraged by the small size and immature appearance of small pediatric kidneys and reluctant to use them in SKTs for the scruple on recovery of renal function. The EBKTs was developed in part to alleviate this scruple by doubling the renal nephron mass. But in this study, our observations on graft function suggested that SKTs from donors of ≤10 kg could do as well as EBKTs. Similar eGFR was observed in both groups immediately after transplant and the eGFR could increase steadily till 2-year posttransplant, reaching at median 100 mL/min/1.73 m^2, with no significant differences between the SKT and EBKT groups. Moreover, consecutive ultrasound examination presented continuous increase in the size of the kidney during the first year posttransplant, which was attributed to by compensatory hypertrophy of nephrons in response to increasing metabolic demand by adult recipients (31). The satisfactory and comparable recovery of renal function and substantial increase in graft size guaranteed the outcomes of SKTs from very small donors (donor weight ≤10 kg) to adult recipients in suitable donor and recipient scenarios.

Another major concern that limits the development and promotion of SKTs from small pediatric donors to adult recipients is high risk of technical complications (32). However, technical complications showed a very low rate in our study, which was in consistent with previous reports (14,24). The *en bloc* concept evolved in part to decrease the risk of vascular thrombosis and anastomotic stricture or occlusion by handling larger aorta and vena cava instead of small renal vessels (33). However, our study showed no significant differences in the rate of complications between the SKT and EBKT groups. In particular for vascular complications, no vascular thrombosis was observed in the SKT group and only one patient happened to artery stenosis but was resolved and maintained favorable graft function. Vascular complications could be ascribed not only to small vessels, but also to torsion of vessels and dislocation of grafts. A study demonstrated higher likelihood of vessel torsion in EBKTs as compared to SKTs from pediatric donors younger than 5 years (33). Moreover, single kidney grafting is more operable and could avoid the difficulty of correct positioning of *en bloc* grafts and the associated risk of vascular torsion (33). Therefore, by adopting the aortic patch for anastomosis, suitable anticoagulation protocol and direct papaverine injection before reperfusion, SKTs could reduce the risk of vascular complications and show surgical advantages. Moreover, it is worth noting that EBKT and SKT were evenly distributed in the whole follow-up timeline and therefore experience bias can be ignored.

Hyperfiltration injury has always been a concern when talking about SKTs in adult recipients using small pediatric kidneys. Early physiologically inadequate renal mass and excess blood perfusion result in hyperfiltration injury and it's indicated by early onset of proteinuria (34,35). It has been reported that proteinuria can be observed in 40–70% patients receiving pediatric kidney transplantation 1-year posttransplant (33,36). In our study, a higher incidence of proteinuria was also noted. But it may be partly explained by the relatively low criteria (urinary protein test ±) for diagnosing proteinuria. In addition, persistent hyperfiltration injury could increase the risk of developing glomerulosclerosis and even progressing to focal segmental glomerulosclerosis. Fortunately, the percentage of patients with proteinuria declined gradually and most of the proteinuria subsided during the follow-up period. Also, no graft loss caused by hyperfiltration injury was observed in our study. Thus, the occurred hyperfiltration injury may be transient until the kidneys hypertrophy and adapt to the recipients' demand. Nonetheless, strict control of blood pressure and attentive follow-up should be warranted to minimize the hyperfiltration injury when using small pediatric kidneys in SKTs.

The results of our study should be interpreted after acknowledgement of its limitations. The main limitation of our study is the relatively small cohort size, yet this is the first and largest reported single-center cases of comparing outcomes of SKTs and EBKTs from donor weighing ≤10 kg. And the differences of donor weight between two groups was caused by the general allocation procedure, because organ allocation was made before recovery of organs in clinical scenarios. Moreover, long-term data is still unavailable at present. Therefore, to maximize utilization and avoid discarding organs, we expect further investigation

in a multicenter study on a larger cohort scale and longer follow-up time to promote SKTs from very small pediatric donors.

Kidneys from small pediatric donors particularly those weighing ≤10 kg are underutilized for transplantation. Our study provided evidence that single kidney transplant from pediatric donors weighing ≤10 kg into adult recipients is associated with satisfactory graft function and graft survival and minimal complications, comparable with the outcomes of *en bloc* kidney transplants in certain donor and recipient scenarios. Importantly, this study makes a contribution for further expansion of the kidney donor pool by providing convincing evidence of conducting SKTs from very small pediatric donor kidneys to adult recipients.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the institutional ethics committee of the First Affiliated Hospital of Sun Yat-sen University {No. [2016]086} and individual consent for this retrospective analysis was waived.

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