Comparable Short- And Intermediate-Term Outcomes In Recipients of Single Kidney Transplants From Small *Vs.* Big Pediatric Donors

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Research article

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Abstract

Purpose: To optimize the use of Single kidney transplantation (SKT) and evaluate outcomes in recipients of single kidney transplants from small pediatric donors, compared to big pediatric donors.

Methods: A total of 85 SKTs from pediatric donors (≤18 years-old) were performed in our hospital between 2015 and 2020. Outcomes were compared for recipients of small donors (≤8 years-old; small-kidney group [SKG], n = 38) and big donors (9–18 years-old; big-kidney group [BKG], n = 47).

Results: The SKG and BKG had no significant differences in patient survival at 1 year (100% *vs.* 100%), 3 years (100% *vs.* 97.0%), and 5 years (100% *vs.* 97.0%) and in graft survival at 1 year (97.4% *vs.* 97.9%), 3 years (92.9% *vs.* 94.9%), and 5 years (92.9% *vs.* 94.9%). The 5-year death-censored graft survival was 100% in the SKG and 97.9% in the BKG. The rate of transplant renal artery stenosis (TRAS) was significantly greater in the SKG than the BKG (18.4% *vs.* 4.3%, P = 0.039).

Conclusion: The clinical outcomes achieved by performing SKT from small pediatric donors are comparable to those achieved for SKT from big pediatric donors. These results support the use of SKT from young pediatric donors.

Trial registration: (ClinicalTrials, gov number: ChiCTR2100044055)

Introduction

Patients with end-stage renal disease (ESRD) can be treated by dialysis or ideally by kidney transplantation. Transplantation has advantages over dialysis in terms of patient survival and quality of life [1–3]. However, the limited supply of organs remains a significant obstacle [4, 5]. This has led to the use of kidneys from deceased pediatric donors [6]. However, due to technical complications, vascular complications, and hyperfiltration injury, many transplant units are still reluctant to use the small kidneys from pediatric donors [7–13]. Recent studies reported excellent patient and graft survival in patients with ESRD who received pediatric en bloc kidneys (PEBKs) [14–18]. In particular, Rogers et al. [14] performed 34 PEBK transplants (donor age ≤ 3 years) and 73 adult en bloc kidney (EBK) transplants. The PEBK group had higher patient survival (88% *vs.* 62%) and graft survival (71% *vs.* 44%) after a mean follow-up period of 7.8 years. Although the transplantation of PEBKs has achieved good results, the routine transplantation of two kidneys into one patient does not maximize the use of limited kidney resources.

Because single kidney transplantation (SKT) provides treatment for more recipients, some units use this method for pediatric donors, and have achieved results similar to those from PEBKs or ideal deceased donor transplantation [7–10, 15]. For example, Mohanka et al. [8] reported that overall 1-year graft survival in pediatric SKT recipients (86%, n = 14) was similar to that of recipients of PEBKs (75%, n = 19, P = 1.000), and Gröschl et al. [9] reported the 3-year death-censored graft survival rate was 100% for recipients of pediatric SKT (n = 15). Nonetheless, SKT from pediatric donors remains rare [6, 15], and the utilization rate decreases as donor weight decreases [6, 15]. Data from the Scientific Registry of Transplant Recipients showed that the recovery rate was 90.8% when the donor body weight was 10 to 21 kg, but was only 42.9% when the donor body weight was less than 10 kg [6]. Similarly, recent data from the National Health Service Blood and Transplant (NHSBT) showed low overall kidney utilization rate from young donors (<2 years-old: 36%; 2–5 years-old: 71%; 5–18 years-old: 96%) [15].

To optimize the use of SKT from small pediatric donors, we compared short- and intermediate-term patient and death-censored graft survival of recipients of small pediatric kidneys (≤8 years-old) and big pediatric kidneys (9–18 years-old). We also compared the incidence of post-transplant complications (pulmonary infection, delayed graft function, artery stenosis, acute rejection, primary nonfunction [PNF]) in these two groups.

Materials And Methods

Study Population

This retrospective cohort study was performed between January 2015 and May 2020 at the Second Affiliated Hospital of University of South China. Twenty-two en bloc renal allografts from deceased pediatric donors who were 8 years-old or younger were separated, thus providing 38 single renal allografts for transplantation into recipients in the small-kidney group (SKG) and 6 single allografts that were allocated to other hospitals. 47 SKTs from deceased pediatric donors who were 9 to 18 years-old were performed during the same time period for transplantation into recipients in the big kidney group (BKG) and 3 single allografts that were allocated to other hospitals. All recipients had ESRD, were younger than 60 years-old, and had BMIs less than 30 kg/m^2.

All pediatric donor grafts were donated to the Red Cross Society of Hunan Province and allocated by the China Organ Transplant Response System. No organs were obtained from prisoners in this study. The study procedures were approved by the ethics committee at The Second Affiliated Hospital of the University of South China and performed in accordance with the national program for deceased organ donation in China [19]. The deceased donor category was donation after brain death followed by circulatory death (DBCD) [20]. All clinical and research activities were consistent with the principles in the 2018 version of the Declaration of Istanbul on Organ Trafficking and Transplant Tourism [21].

Transplant Procedures

All pediatric donor grafts were removed and flushed with hypertonic citrate-adenine (HCA) solution until there was no remaining blood. Then, the small arteriovenous branches of the graft were ligated, the excess fat tissue on the graft surface was freed and removed, and the graft ureter was trimmed. Because the donor renal vein was not long enough and the transplantation was difficult, the inferior vena cava of the donor was taken for extension, using a continuous 5-0 Prolene suture. The trimmed graft was stored in a hypothermic perfusion solution.

For kidney transplantation, anesthesia was applied and the patient was placed in a supine position. The perineum and external urethra were disinfected, and a 16 F urinary catheter was placed into the bladder through the urethra. About 100 mL of sterile gentamicin saline was introduced into the bladder, and then the catheter was clamped temporarily. A lower abdominal L-shaped incision (about 15 cm) was used. The incision was disinfected and draped. Then, the iliac fossa was exposed, and the external iliac vein and internal iliac artery were separated. After partially blocking the external iliac vein, part of the vein wall of the external iliac vein was cut longitudinally, and the venous lumen was flushed with heparin-saline. The donor renal vein and external iliac vein were joined using end-to-side anastomosis with a 5-0 Prolene suture. The proximal and distal ends of the internal iliac artery were then blocked and freed completely. The distal end of the internal iliac artery was sutured with a 2-0 silk thread and ligated with 1-0 silk thread. The donor renal artery and the proximal incision of the internal iliac artery were joined using end-to-end anastomosis with a 6-0 Prolene suture. None of the cases had obvious bleeding at the anastomosis. After the renal vein slackened, the renal artery was loosened and the flow of urine from the graft ureter was confirmed. Anastomosis of the graft ureter to the urinary bladder of the recipient was performed using the bladder inverted papillary anti-reflux technique with a double J stent inside.

Immunosuppression

All recipients received induction therapy with basiliximab and maintenance immunosuppression with tacrolimus, combined with mycophenolate mofetil and corticosteroids. Intravenous basiliximab (20 mg/day) was given on the day of transplantation (day 0) and on day 4. Intravenous methylprednisolone (500 mg/day) was given from day 0 to day 2, followed by oral methylprednisolone (50 mg/day) which was tapered to a maintenance dose (4 mg/day). Oral mycophenolate mofetil (0.25 g/day) was administered on day 0, and the maintenance dose was adjusted according to

clinical manifestations or blood concentration. Oral tacrolimus (1 mg/kg) began on day 1 and was adjusted according to blood concentration; the targeted trough level was 8 to 10 ng/mL initially, and 6 to 8 ng/mL after 3 months.

Data Collection

The electronic clinical records system of The Second Affiliated Hospital of the University of South China was consulted to retrieve renal transplantation data and hospitalizations in all consecutive donors and recipients from January 2015 to May 2020. The last follow-up was on August 1, 2020. The baseline characteristics and cause of death in the two donor groups were compared, as were the baseline characteristics of the two recipient groups. The post-transplantation outcome measures were patient survival, graft survival and death-censored graft survival. The secondary outcome measures were incidence of PNF and delayed graft function (DGF), rate of vascular complications, frequency of rejection and infection, incidence of graft removal, and post-transplant SCr level. DGF was defined as the need for more than 1 dialysis session within 1 week after surgery, and graft loss as resumption of dialysis, allograft nephrectomy, or patient death. PNF was defined as a lack of graft function at 6 months after transplantation that was not attributable to an identifiable cause, with the recipient never being dialysis-free after transplantation. Acute rejection was suspected if there was an unexplained 25% increase in SCr level relative to baseline, and was confirmed in most cases by percutaneous kidney biopsy.

Statistical Analysis

Categorical variables were expressed as percentages. Continuous variables were expressed as means with standard deviations if they had normal distributions, and otherwise as medians and ranges. The baseline characteristics of the SKG and BKG groups were compared using Student's *t*-test for continuous variables with normal distributions, and using the Mann-Whitney rank sum test for variables with non-normal distributions or unequal variances. P values were calculated using the Chi-square test or Fisher's exact test for categorical covariates. Graft survival and patient survival were analyzed using the Kaplan-Meier method, and compared using the log-rank test. All statistical analyses were performed using SPSS version 26 and GraphPad Prism version 8.0.1.

Results

Patient Population

The patient cohort consisted of 38 individuals in the SKG (who received transplants from 22 pediatric donors who were 8 years-old or younger) and 47 individuals in the BKG (who received transplants from 25 pediatric donors who were 9–18 years-old). We initially compared the characteristics of the donors and recipients (Tables 1 and 2, Figure 1). Donors to the SKG were younger (median age: 5 *vs.* 13 years, P < 0.001), weighed less (mean: 20.1 *vs.* 47 kg, P < 0.001), and had a lower BMI (median: 16.55 *vs.* 19 kg/m^2, P = 0.015). The donors to both groups were mostly male. The causes of death in donors to the SKG were intracerebral hemorrhage (n = 2), brain trauma (n = 12), aplastic anemia (n = 3), brain tumor (n = 2), and respiratory-circulatory failure due to other causes (n = 3). The causes of death in donors to the BKG were intracerebral hemorrhage (n = 7), brain trauma (n = 15), aplastic anemia (n = 2), brain tumor (n = 0), and respiratory-circulatory failure due to other causes (n = 1). Overall, the causes of death were similar in these groups (P = 0.206). These groups also had similar percentages of different blood types (A: 40.9% *vs.* 36%, B: 18.2% *vs.* 8%, AB: 13.6% *vs.* 8%, O: 27.3% *vs.* 48%; P = 0.460).

Table 1
Demographic and clinical characteristics of small kidney donors (n = 22) and big kidney donors (n = 25).

	Small (≤8 years-old)	Big (9–18 years-old)	P
Age, median (range), years	5.0(2.75–7.0)	13(11–16)	<0.001
Male, n (%)	14(63.6)	16(64)	0.979
Body weight, mean ± SD, kg	20.1±5.8	47±11.9	<0.001
BMI, median (range), kg/m^2	16.55(14.65–19.25)	19(16.55–21.4)	0.015
Cause of death, n (%)			0.206
Intracerebral hemorrhage	2(9.1)	7(28)	–
Brain trauma	12(54.5)	15(60)	–
Aplastic anemia	3(13.6)	2(8)	–
CNS tumor	2(9.1)	0(0)	–
Others	3(13.6)	1(4)	–
Blood type, n (%)			0.460
A	9(40.9)	9(36)	–
B	4(18.2)	2(8)	–
AB	3(13.6)	2(8)	–
O	6(27.3)	12(48)	–

BKG, big-kidney group; BMI, body mass index; CNS, central nervous system; SKG, small-kidney group; SD, standard deviation

Table 2
Demographic and clinical characteristics of the SKG (n = 38) and BKG (n = 47).

	SKG	BKG	P
Age, mean ± SD, years	37.7±10.7	38.1±11.2	0.86
Body weight, median (range), kg	55.75(50–65)	54(48–65)	0.496
BMI, mean ± SD, kg/m^2	20.9±2.7	20.7±3.8	0.752
ESRD duration, median (range), months	24(6–60)	24(12–60)	0.323
Pretransplant dialysis, median (range), months	12.5(3–36)	14(6–37)	0.413
LOS, median (range), days	32.5(28.75–37)	31(29–34)	0.467
Last preoperative creatinine, mean ± SD, μmol/L	904.4±313.7	972.3±360.1	0.362
WIT, median (range), min	17.5(11–24.5)	20(14–24)	0.093
CIT, median (range), h	2.95(2.3–4.025)	2.5(2.3–3.3)	0.153
Female, n (%)	11(28.9)	12(25.5)	0.725
Blood type, n (%)			0.222
A	15(39.5)	18(38.3)	–
B	6(15.8)	4(8.5)	–
AB	6(15.8)	3(6.4)	–
O	11(28.9)	22(46.8)	–
Primary disease, n (%)			0.94
Chronic glomerulonephritis	29(76.3)	36(76.6)	–
Polycystic kidney	3(7.9)	4(8.5)	–
IgA nephropathy	2(5.3)	3(6.4)	–
Others	4(10.5)	4(8.5)	–
Type of dialysis, n (%)			0.273
Hemodialysis	30(78.9)	41(87.2)	–
Peritoneal dialysis	6(15.8)	6(12.8)	–
Pre-emptive transplant	2(5.3)	0	–
Follow-up, median (range), months	34.7(17.1–46.7)	25.4(16.3–44.9)	0.730

BKG, big-kidney group; BMI, body mass index; CIT, cold ischemia time; LOS, length of stay; SD, standard deviation; SKG, small-kidney group; WIT, warm ischemia time

The recipients in the SKG and BKG had no differences in age, gender, body weight, BMI, duration of ESRD, pretransplant dialysis duration, LOS, last preoperative SCr level, warm ischemia time, cold ischemia time, blood type, primary disease, and type of dialysis (Table 2 and Figure 1). The median follow-up time was 34.7 months in the SKG (range: 17.1–46.7 months) and 25.4 months in the BKG (range: 16.3–44.9 months).

Early Graft Function

PNF was less common in the SKG than the BKG, but this difference was not significant (0 *vs.* 8.5%, P = 0.184; Table 3). DGF was more common in the SKG than the BKG, but this was also not significant (50.0% *vs.* 29.8%, P = 0.074). Repeated measures ANOVA of the SCr levels (Figure 2) indicated a significant effect of time at 2 weeks after transplant (P < 0.001) and 1 month after transplant (P = 0.004). In other words, the SCr levels of patients decreased significantly over time. However, the 2 groups differed in early graft function recovery. In particular, the rate of SCr decline was slower in the SKG on day-14 (mean SCr: 302 ± 311 μmol/L *vs.* 163 ± 202 μmol/L, P = 0.005) and on day-28 (mean SCr: 142 ± 74 μmol/L *vs.* 103 ± 49 μmol/L, P = 0.003). However, there was no interaction effect between group and time on day 14 (P = 0.065) or day 28 (P = 0.129).

Table 3
Complications in the SKG (n = 38) and BKG (n = 47).

	SKG	BKG	P
Pulmonary infection, n (%)	20 (52.6)	28 (59.6)	0.521
Delayed graft function, n (%)	19 (50.0)	14 (29.8)	0.074
Artery stenosis, n (%)	7 (18.4)	2 (4.3)	0.039
Acute rejection, n (%)	7 (18.4)	10 (21.3)	0.743
Primary nonfunction, n (%)	0	4 (8.5)	0.184
Graft loss, n (%)	2 (5.3)	2 (4.3)	>0.999
Death, n (%)	0	1 (2.1)	>0.999
Death-censored graft loss, n (%)	0	1 (2.1)	>0.999

Post-transplant Infections and Graft Loss

Analysis of complications indicated the two groups had no significant differences in pulmonary infection (52.6% [SKG] *vs.* 59.6% [BKG], P = 0.521) or graft loss (5.3% [SKG] *vs.* 4.3% [BKG], P > 0.999). Two patients in the SKG lost allografts; one was removed by nephrectomy on day 2 after transplantation due to hyperacute rejection (HAR), and one lost function at 26 months after transplantation, leading to the need for dialysis. Two patients in the BKG also lost allografts; one was removed on day 9 after transplantation because of acute rejection, and one lost function at 18 months after transplantation.

Graft and Patient Survival

Almost all recipients in both groups achieved satisfactory renal function. During the follow-up (SKG median = 34.7 months, BKG median = 25.4 months), the two groups had no significant differences in patient survival at 1 year (SKG: 100%, BKG: 100%, P = 0.384), 3 years (SKG: 100%, BKG: 97.0%; P = 0.384), and 5 years (SKG: 100%, BKG: 97.0%, P = 0.384; Figure 3A) and no significant differences in graft survival at 1 year (SKG: 97.4%, BKG: 97.9%, P = 0.864), 3 years (SKG: 92.9%, BKG: 94.9%, P = 0.864), and 5 years (SKG: 92.9%, BKG, 94.9%, P = 0.864; Figure 3B). In addition, none of the 38 patients in the SKG died after transplantation due to graft loss or other reasons, leading to death-censored graft survival rate of 100% (Table 3). One patient in the BKG died due to graft loss, leading to a death-censored graft survival rate of 97.9%.

Graft Acute Rejection

The incidence of acute rejection was lower in the SKG, but this difference was not significant (18.4% *vs.* 21.3%, P = 0.743; Table 3). Notably, one patient in the SKG lost his graft due to severe irreversible HAR and one patient in the BKG lost his

graft due to acute rejection and PNF (Table 3). All other grafts in both groups were rescued after treatment.

Vascular Complications

The rate of transplant renal artery stenosis (TRAS) was significantly greater in the SKG (18.4% *vs.* 4.3%, P = 0.039). We therefore performed a more detailed analysis of these 9 patients (Table 4). Eight of them had pre-transplant hypertension, all had BMIs less than 25 kg/m^2, and 6 had BMIs less than 20 kg/m^2. All 7 SKG patients with TRAS progressed to DGF after transplantation, but the 2 BKG patients with TRAS did not progress to DGF. Furthermore, 3 SKG patients with TRAS experienced acute rejection, but the 2 BKG patients with TRAS did not. Notably, no patient in either group progressed to acute kidney injury (AKI) or lost grafts, and all patients recovered well after therapy.

Table 4
Details of artery stenosis in patients in the SKG (n = 7) and BKGD (n = 2).

Graft #	Donor age	Recipient age, sex	BMI kg/m^2	CMV	Pre-Tx Hypertension	DGF	Acute rejection	End-to-end arterial anastomosis	AKI	Outcome
1	4	42, M	19.61	–	–	+	+	+	No	Recovery
2	2.42	34, F	18.83	–	+	+	+	+	No	Recovery
3	6	46, M	21.45	–	+	+	–	+	No	Recovery
4	7	34, M	17.01	–	+	+	–	+	No	Recovery
5	3	54, F	20.55	–	+	+	–	+	No	Recovery
6	7	34, F	23.19	–	+	+	–	+	No	Recovery
7	4	28, F	18.59	–	+	+	+	+	No	Recovery
8	16	57, M	19.83	–	+	–	–	+	No	Recovery
9	13	28, M	19.49	–	+	–	–	+	No	Recovery

AKI, acute kidney injury; BMI, body mass index; F, female; CMV, cytomegalovirus; M, male; Tx, transplantation; DGF, delayed graft function

Discussion

The worldwide organ shortage has led to the search for additional sources of kidneys. Many transplant units use PEBK for transplantation from pediatric donors because of their small size. Although this provides excellent clinical outcomes, pediatric SKT would be ideal. However, there are no guidelines or established consensus regarding the allocation and use of single kidneys from small pediatric donors. In the past 5 years, we performed 85 SKTs from pediatric donors. Previous studies compared the outcomes of SKT using adult deceased kidney donors, ideal kidneys, and PEBK [6–10, 15, 22–26]. We compared the short- and intermediate-term patient survival, graft survival and death-censored graft survival of SKTs from small pediatric donors (≤8 years-old) and big pediatric donors (9–18 years-old).

Only a few studies examined SKTs from small pediatric donors (≤8 years-old), and the results varied greatly. For example, a 2006 study of small pediatric donors using data from the Scientific Registry of Transplant Recipients (SRTR) compared the risk of graft loss following PEBK, pediatric SKT, and ideal donors. These authors reported that pediatric SKT had a 78% greater risk of graft loss than PEBK [6]. More recent SRTR data showed that recipients of pediatric SKT, ideal donors, and PEBK led to comparable patient survival and death-censored graft survival [26]. However, the other studies which reported excellent patient and graft survival after pediatric SKT were limited by small sample sizes [8, 9, 24, 27, 28]. For instance, a 2013 single-center study examined pediatric SKT in 10 child recipients and 4 adult recipients [28].

The children had 5-year patient and graft survivals of 100%, but the adults had a 5-year patient survival of 100% and a 5-year graft survival of 75% (1 lost graft). Mohanka et al. [8] reported the 1-year graft survival was 86% for SKT from small donors (≤15 kg), but only examined 14 recipients. Gröschl et al. [9] reported the 3-year death-censored graft survival after SKT from small donors was 100% in 15 recipients. Sharma et al. [24] reported the 5-year patient survival was 81% and the death-censored graft survival was 84% after SKT from small donors (mean donor weight: 27 kg) in 31 recipients. Balachandran et al. [27] reported that pediatric SKT (≤10 kg) in 11 recipients yielded excellent short-term outcomes, with a 2-year patient survival of 100% and graft survival of 92.5%. Although these previous results appear promising, they all examined small numbers of recipients.

We performed 38 SKTs from small pediatric donors (≤8 years-old, median body weight = 20.1 kg). Our results indicated excellent renal function in all recipients, indicating rapid compensatory hypertrophy of the small single renal allografts. The SCr level of the recipients in the SKG declined rapidly after surgery, and was nearly normal 1 month later. During the early stage after transplantation (1 month) the SCr level decreased more slowly in the SKG than the BKG, but we believe these groups will tend to have the same or similar SCr levels over time. Our two recipient groups also had similar 1-year graft survival (97.4% *vs.* 97.9%), 3-year graft survival (92.9% *vs.* 94.9%), 5-year graft survival (92.9% *vs.* 94.9%), and 5-year death-censored graft survival (100% *vs.* 97.9%). Impressively, there were no graft failures and no patients died in the SKG during the 5-year follow-up period. Thus, our results provide important clinical support regarding the effectiveness of SKT from young pediatric donors, a procedure that will make more kidneys available for transplantation.

A 2019 study of 46 SKTs from small pediatric donors reported the death-censored graft survival rate was 100% [29], encouraging results and in line with our results. Notably, this prior study reported the 1-year survival rate of recipients of small SKTs was 89.1%, although none of these deaths could be directly linked to the small allograft size. We should also note that the recipients of small SKTs in this prior study were carefully selected, with priority given to women who had relatively low body weight (median weight of the SKG = 46.5 kg). However, in present study we achieved a 5-year patient survival of 92.9% and a 5-year death-censored graft survival of 100% using less stringent criteria for recipient selection. Thus, the previously reported success was with low body weight recipients, but our current results apply more generally to patients with ESRD. In agreement, another large-scale analysis of SRTR data in the United States [26] also reported encouraging outcomes of SKT from small pediatric donors (<8 years-old, body weight < 30 kg). Thus, our data indicate high success of pediatric SKT for Chinese recipients.

The high incidence of post-transplant complications is a major cause for poor recovery following SKT [6, 30]. Although there are no prospective studies of TRAS and only a few large-scale retrospective studies, TRAS is a critical issue that deserves increased attention. In particular, TRAS is a serious complication that can occur after kidney transplantation and lead to uncontrollable hypertension and renal dysfunction. One of the most common post-transplantation complications is premature renal failure, and TRAS is a major cause of this complication. Therefore, early diagnosis and treatment of renal artery stenosis is very important. Previous studies reported the prevalence of TRAS ranged from 1–23% [31]. Data from USRDS registry indicated the adjusted hazard ratio (aHR) for graft loss and death in patients with TRAS was 2.84 (95% CI = 1.70–4.72) [32].

In the present study, the overall incidence of graft renal artery stenosis was 10.6%, although TRAS was significantly more common in the SKG than the BKG (18.4% *vs.* 4.3%, P = 0.039). We speculate that TRAS may be related to preoperative hypertension and DGF. Moreover, recipients with DGF in the SKG may be more likely to develop this complication, as also reported previously. For example, two studies reported that the independent risk factors for TRAS were recipient BMI greater than 30 kg/m^2, cytomegalovirus (CMV) infection, and DGF [32, 33]. More specifically, Hurst et al. [32] reported that TRAS was related to DGF (aHR: 1.34, 95% CI: 1.13–1.60, P = 0.001) but not CMV. Kamali et al. [33] reported that recipient BMI greater than 30 kg/m^2 (relative risk [RR]: 7.97, 95% CI: 3.44–18.46, P < 0.001), CMV infection (RR: 4.29, 95% CI: 3.79–13.29, P = 0.01), and DGF (RR: 4.29, 95% CI: 3.12–13.79, P = 0.01) were significantly and independently related to TRAS.

Although these two studies reported contradictory findings regarding the effect of CMV, our results showed that all patients with TRAS were negative for CMV (Table 4). This is probably due to our routine use of antiviral therapy before transplantation.

In the present study, we used end-to-end arterial anastomosis to suture the transplant renal artery and internal iliac vessels in all 9 patients who had TRAS. Thus, TRAS may be a consequence of this suture technique. Smith et al. [34] and Fung et al. [35] also reported that patients who received end-to-end arterial anastomosis were more likely to develop TRAS, but other studies found no difference in TRAS following end-to-end *vs.* end-to-side anastomosis [36, 37]. However, all these results were from retrospective studies that had small sample sizes. Thus, further prospective studies are needed to determine the effect of different arterial anastomosis methods on the incidence of TRAS.

Short-term complications after transplantation are one of the major reasons for hesitancy in using small pediatric SKT [6, 8, 25, 38]. Mohanka et al. [8] reported that DGF was 25% and acute rejection was 21% among recipients of pediatric SKT. In our SKG, the incidence of DGF was 50.0% and the incidence of acute rejection was 18.4%. Although the incidence of DGF in our SKG was higher than in the abovementioned study, our two recipient groups had no statistically significant difference in DGF. In addition, our two recipient groups also had no differences in pulmonary infection and PNF. We attribute this partly to our use of refined surgical techniques, carefully managed immunosuppressive therapy, and experience in perioperative management.

Our study had some limitations. First, it was limited by the retrospective design, so the results may be subject to bias. Second, our sample size was relatively small. In spite of these shortcomings, our data provide more evidence to support the use of SKT from small pediatric donors.

In conclusion, our study showed that excellent 1-year, 3-year, and 5-year patient and graft survival and 5-year death-censored graft survival can be achieved by SKT from small pediatric donors, and that the results were similar when the donors were 8 years-old or less or 9 to 18 years-old. Although short-term complications after transplantation were common, appropriate management led to satisfactory clinical results. In short, SKT from pediatric donors doubles the number of potential recipients. Large prospective studies of this topic are eagerly anticipated.

Declarations

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Authorship All authors jointly agreed upon the outline of the paper. Zhanchen Liao participated in performance of the research, data analysis, and writing of the article. Zhanchen Liao and Tao Jiang contributed equally to this work. Yiqi Liu participated in research design, data analysis, and preparation of the figures. Zhigang Luo made substantial contributions to the conception of the work and interpretation of data, performed most of the surgeries, and critically revised the article.

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Conflict of interest The authors declare no conflicts of interest.

Ethics approval This is an observational study. The ethics committee at The Second Affiliated Hospital of the University of South China has confirmed that no ethical approval is required. No organs were obtained from prisoners in this study.

Informed consent The need for informed consent was waived in view of the retrospective and observational nature of the study.

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Figures

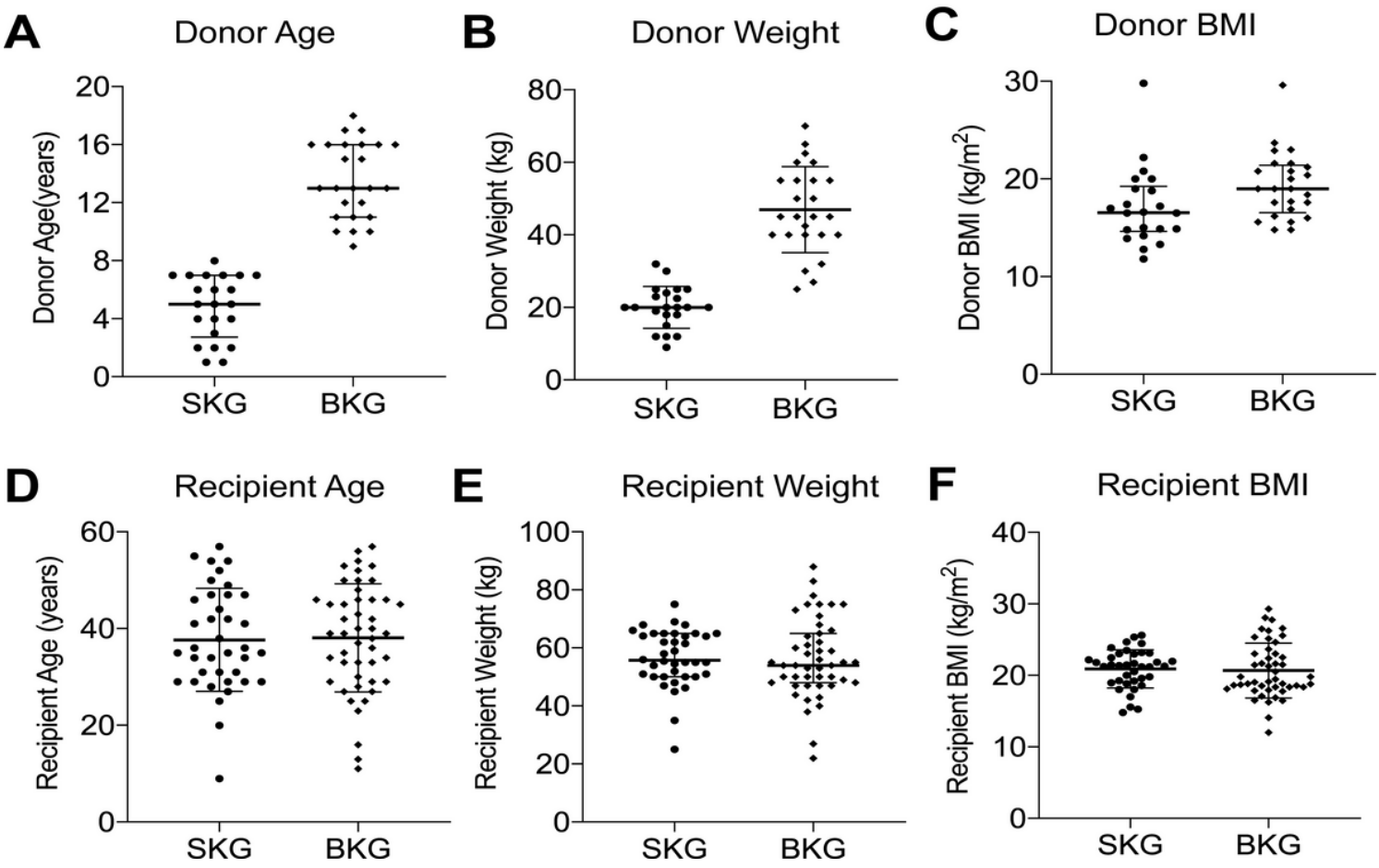

Figure 1

Comparisons of donor age (A; P < 0.001), donor body weight (B; P < 0.001), donor BMI (C; P = 0.001), and of recipient age (D; P = 0.86), recipient body weight (E; P = 0.496), and recipient BMI (F; P = 0.752) in the small-kidney group (SKG) *vs.* the big-kidney group (BKG)

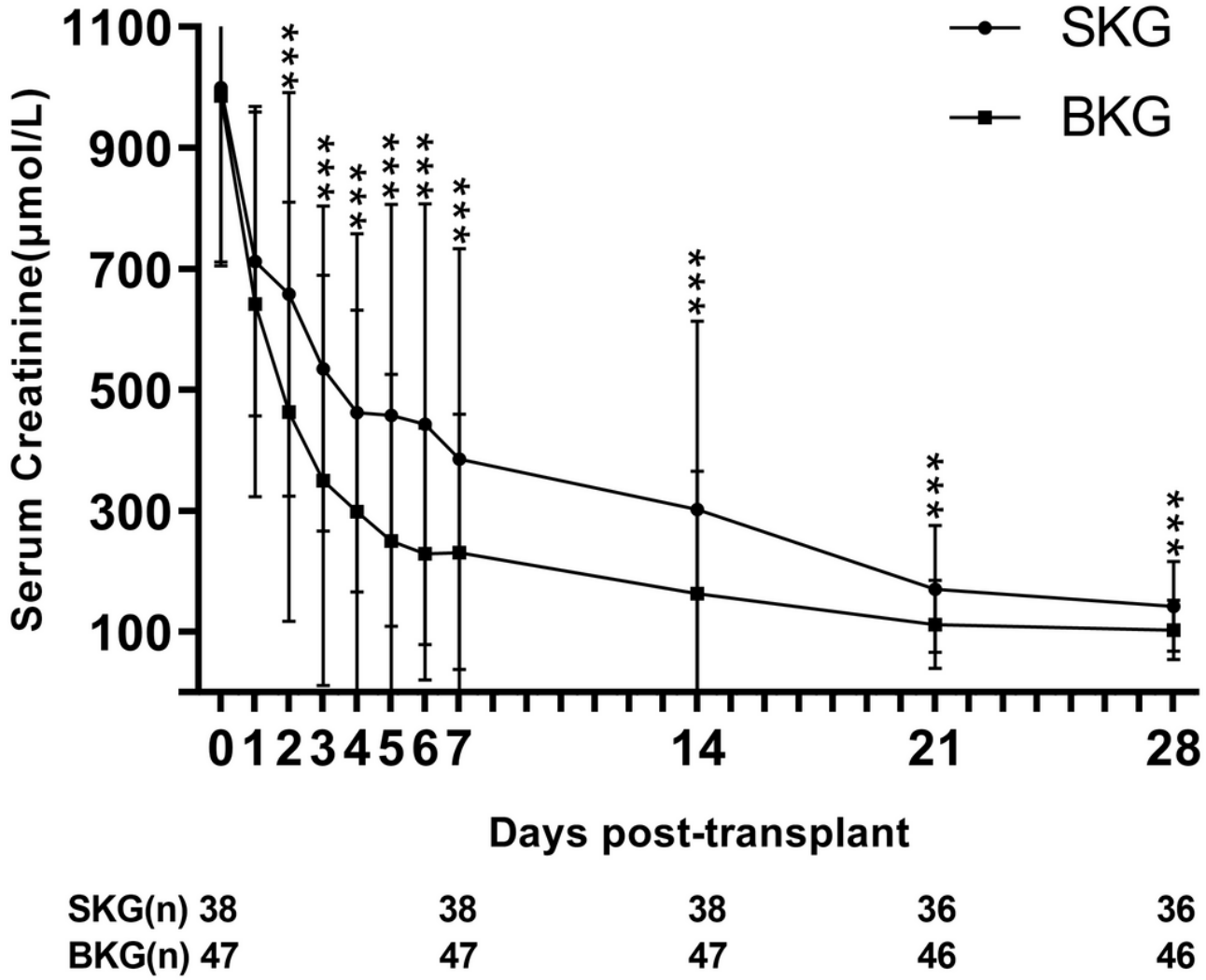

Figure 2

Changes in mean serum creatinine levels in the small-kidney group (SKG) and the big-kidney group (BKG) during the first month posttransplantation. Bars, standard deviations; ***, significant difference between groups (P < 0.05)

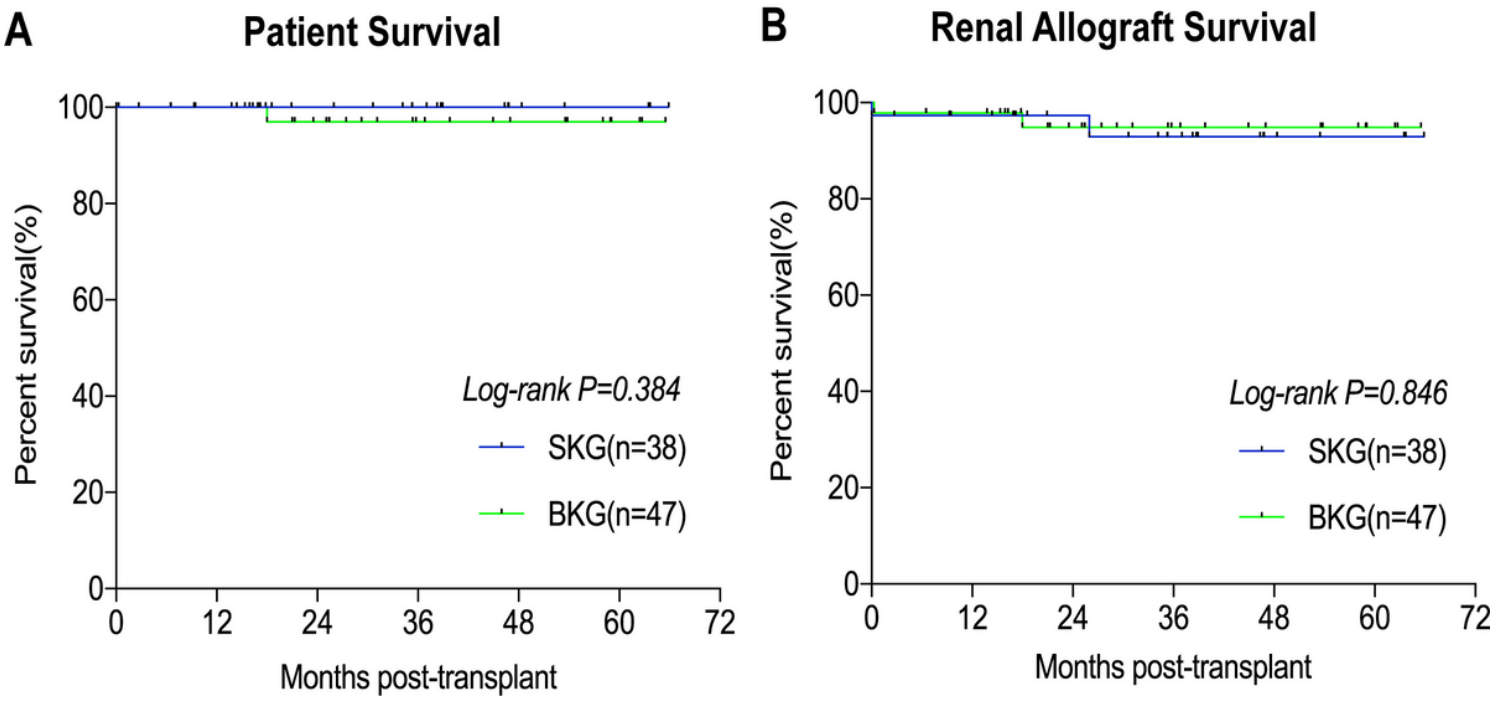

Figure 3

Kaplan-Meier analysis of patient survival (A) and renal allograft survival (B) in the small-kidney group (SKG) and the big-kidney group (BKG). The two groups had no significant differences in patient survival (P = 0.384, log-rank test) or renal allograft survival (P = 0.864, log-rank test). The 1-, 3-, and 5-year patient survival rates were 100%, 100%, and 100% in the SKG group and 100%, 97.0%, and 97.0% in BKG group. The 1-, 3-, and 5-year renal allograft survival rates were 97.4%, 92.9%, and 92.9% in the SKG group and 97.9%, 94.9%, and 94.9% in BKG group