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Robotic kidney transplantation in the obese patient: 10-year experience from a single center

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Despite increasing obesity rates in the dialysis population, obese kidney transplant candidates are still denied transplantation by many centers. We performed a single-center retrospective analysis of a robotic-assisted kidney transplant (RAKT) cohort from January 2009 to December 2018. A total of 239 patients were included in this analysis. The median BMI was 41.4 kg/m^2, with the majority (53.1%) of patients being African American and 69.4% of organs sourced from living donors. The median surgery duration and warm ischemia times were 4.8 hours and 45 minutes respectively. Wound complications (mostly seromas and hematomas) occurred in 3.8% of patients, with 1 patient developing a surgical site infection (SSI). Seventeen (7.1%) graft failures, mostly due to acute rejection, were reported during follow-up. Patient survival was 98% and 95%, whereas graft survival was 98% and 93%, at 1 and 3 years respectively. Similar survival statistics were obtained from patients undergoing open transplant over the same time period from the UNOS database. In conclusion, RAKT can be safely performed in obese patients with minimal SSI risk, excellent graft function, and patient outcomes comparable to national data. RAKT could improve access to kidney transplantation in obese patients due to the low surgical complication rate.

KEYWORDS

clinical research/practice, disparities, health services and outcomes research, kidney transplantation/nephrology, obesity, surgical technique

1 | INTRODUCTION

The utilization of the minimally invasive approach in transplant surgery is an innovation that is yet to be universally adopted. More recently, robotic-assisted techniques have allowed for increased visual field perception, essential for performing deep anastomosis in the pelvis and ergonomic control with three-dimensional navigation.[1] Clinically, patients have shorter hospital stays, minimal postoperative pain, fewer wound infections, and better cosmesis.[2] The first robotic approach to kidney transplant was described by Hoznek in 2001,[3] followed by a variety of unique approaches within the decade.[4] During this time, the first intra-abdominal robotic kidney transplant (RAKT) in an obese patient was performed by our group at the University of Illinois at Chicago in 2009.[5] Despite the encouraging results of this approach, the technique continues to be cautiously adopted.[6]

The idea of applying robotic surgery to kidney transplantation was born out of the need to reduce the morbidity of open kidney transplant in obese candidates.

Our hypothesis is that RAKT when performed in obese candidates can reduce the frequency of surgical site complications as well

Abbreviations: BMI, body mass index; DGF, delayed graft function; eGFR, estimated glomular filtration rate; PNF, primary nonfunction; RAKT, robotic-assisted kidney transplant; SSI, surgical site infection.

as demonstrate favorable short- and long-term outcomes. The present study reports the results of the largest cohort of robotic kidney transplants performed to date.

2 | MATERIALS AND METHODS

2.1 | Study design and patient population

After institutional review board approval, a retrospective analysis of all RAKT performed from January 2009 to December 2018 was conducted. Per protocol, adult patients (>18 years) were considered eligible for RAKT if they had a body mass index (BMI) ≥30 kg/m^2 at the time of listing but excluded in the presence of severe iliac atherosclerosis. Patients with a BMI ≥ 25 kg/m^2 were considered for the procedure if they expressed an interest in the approach, in the absence of any contraindications.

Patient demographic information and intraoperative, postoperative, and follow-up data were obtained from the electronic health record. Data collected also included donor demographics, recipient BMI on day of transplant, dialysis status, and duration of dialysis dependence prior to transplantation.

2.2 | Basic procedural details

A modified version of the totally robotic transabdominal technique described by our group for transplanting the kidney in the right iliac fossa was used.[5] A 30° robotic endoscope is inserted through a 12-mm umbilical trocar, while two 7-mm robotic trocars are inserted in the right subcostal region and left iliac fossa. A 12-mm assistant port is placed between the umbilicus and the trocar positioned in the left iliac fossa. GelPort® access for abdominal organ manipulation is through a 7-cm upper-midline incision.

Details of our immunosuppression protocols have already been published.[2] Briefly, we perform induction with thymoglobulin or basiliximab according to the panel reactive antibody (PRA) values, followed by a 5-day steroid taper and maintenance immunosuppression using a combination of tacrolimus/cyclosporine plus mycophenolic acid.

2.3 | Evaluation of graft function, short- and long-term outcomes

Immunosuppression regimen, delayed graft function (DGF) defined as dialysis within the first week of transplantation, hospital readmissions within 30 days, surgical site infection (SSI) defined as a positive wound culture or presence of wound exudate within the first 30 days from transplant, other wound complications, episodes of rejection, serum creatinine (Cr) and estimated glomerular filtration rate (eGFR) trends, perioperative complications, development of incisional hernias, reoperations, graft failure, and mortality were obtained from chart review. Additional graft and patient survival comparisons were made to kidney transplant patients over the same time period using United Network for Organ Sharing (UNOS) standard transplant analysis and research files.

2.4 | Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics for Macintosh version 25.0 (IBM Corporation, Armonk, NY). Continuous variables were tested for normality using the Shapiro-Wilk test. Categorical variables were described as proportions of the denominator population and reported as percentages. Normally distributed continuous variables were reported as mean ± standard deviation, and nonnormally distributed data were presented as median (interquartile range [IQR]). Pearson's chi-square test was performed to determine differences in categorical variables, and the Student *t* tests and Mann-Whitney U tests were used for normally distributed and nonnormally distributed continuous variables respectively. Kaplan-Meier survival estimates were calculated for both graft and patient survival. A P value < .05 was considered significant.

3 | RESULTS

Over the study period, 248 cases started robotically with a conversion rate of 3.6% (9 patients), leaving 239 RAKTs completed successfully. The reasons for conversion were venous bleeding difficult to control with a minimally invasive approach in 1 patient and poor kidney reperfusion requiring reimplantation in 6 cases. Of these 6, 3 patients had multiple renal arteries that required graft removal and reconstruction of the renal artery, 2 required iliac artery reconstruction for dissection, and 1 patient had a suspected renal artery embolus. Other reasons for conversion were extensive adhesions preventing safe placement of the trocars in 2 patients. Details on these patients are presented in Table 1.

The majority of patients (69.4%) had living donors, and the remaining 30.6% were from deceased donors with a median Kidney Donor Profile Index (KDPI) of 40% (IQR: 35.5, range: 6-91). Thirteen (17.8% of 73 deceased donors) organs were sourced from deceased after cardiac death donors. Donor demographic data are shown in Table 2. Recipient median pretransplant weight and BMI were 119 (range: 67.3-201.2) kg and 41.4 (range: 25.2-62.6) kg/m^2 respectively. Seven patients were overweight (BMI: 25-30) and the other 232 were obese with a BMI > 30. Majority of patients were African American (53.1%). The predominant cause of end-stage renal disease (ESRD) in our cohort was diabetes mellitus and/or hypertension (79.5%) and the median time on dialysis was 44.6 (Range: 0.5-330) months. In 19 cases, the patients had a prior kidney transplant. 8 patients (3.3%) were recipients of organs from ABO-incompatible donors, and another 22 recipients (9.2%) had a positive crossmatch prior to transplant. These patients were subjected to scheduled plasmapheresis sessions preoperatively in the case of living donor

TABLE 1 Cases converted to open renal transplant

S/No	Year	BMI	Gender	Reason for conversion	Details	HLOS	Complications
1	2010	51.2	Female	Impaired visualization	Limited mobilization of bowel from pelvis due to short mesentery	16	Incisional hernia, infected seroma
2	2010	37.1	Male	Poor perfusion/Reimplant	Iliac artery dissection	12	None
3	2010	49.1	Male	Impaired visualization	Extensive adhesions from previous surgery	6	None
4	2013	31.8	Male	Poor perfusion/Reimplant	Arteriotomy too long	6	None
5	2013	36.3	Female	Poor perfusion/Reimplant	Multiple donor arteries on conduit	6	None
6	2014	44	Male	Bleeding	Bleeding from iliac vein	5	None
7	2015	36.8	Male	Poor perfusion/Reimplant	Partial occlusion of artery by atheroma	6	None
8	2018	43.4	Female	Poor perfusion/Reimplant	Iliac artery dissection	11	None
9	2018	36.6	Female	Poor perfusion/Reimplant	Occlusion of accessory donor artery by thrombus	6	None

BMI, body mass index; HLOS, hospital length of stay.

TABLE 2 Donor characteristics

Characteristic	All N = 239	Deceased donor N = 73	Living donor N = 166	*P*
Age (years), median (IQR)	36 (20)	37 (24)	36 (18)	.854
Female sex, n (%)	132 (55.2%)	29 (39.7%)	103 (62%)	.002
Ethnicity and race, n (%)				
Non-Hispanic white	69 (28.9%)	38 (52.1%)	31 (18.7%)	.001
Non-Hispanic black	92 (38.5%)	20 (27.4%)	72 (43.4%)	
Hispanic	54 (22.6%)	13 (17.8%)	41 (24.7%)	
Other/Unknown	24 (10%)	2 (2.7%)	22 (13.2%)	
BMI (kg/m^2), median (IQR)	28.4 (9.9)	25.9 (8.2)	29.4 (9.9)	.008
Weight (kg), median (IQR)	81.5 (29)	79.8 (27.1)	83.4 (30.5)	.155
Creatinine (mg/dL), median (IQR)	0.9 (0.4)	1.2 (0.7)	0.8 (0.3)	<.001
Crossmatch positive, n (%)	22 (9.2%)	1 (1.4%)	21 (12.7%)	.003
Donor type features:				
Related donor, n (%)	106 (44.4%)	NA	106 (63.9%)	
Swap, n (%)	17 (7.1%)	NA	17 (10.2%)	
ABO incompatible, n (%)	8 (3.3%)	0	8 (4.8%)	
DCD, n (%)	13 (5.4%)	13 (17.8%)	NA	
KDPI %, median (IQR)	40 (35.5)	40 (35.5)	NA	
Cause of death, n (%)				
Anoxia	18 (7.5%)	18 (24.7%)	NA	
Stroke	22 (9.2%)	22 (30.1%)	NA	
Head trauma	29 (12.1%)	29 (39.7%)	NA	
CNS tumor	3 (1.3%)	3 (4.1%)	NA	
Other[a]	1 (0.4%)	1 (1.4%)	NA	

Missing values: BMI n = 3; weight n = 6; creatinine n = 1; KDPI n = 5.

BMI, body mass index; CNS, central nervous system; DCD, donation after circulatory death; IQR, interquartile range; KDPI, Kidney Donor Profile Index; n = number of observations.

[a]Brain abscess.

recipients and postoperatively for deceased donor organ recipients. Recipient demographic data are presented in Table 3.

Overall, the median duration of surgery was 4.8 (1.4) hours and the median estimated blood loss was 100 (IQR: 100 mls). The median warm ischemia times (WIT) and cold ischemia times (CIT) were 45.0 (IQR: 13) minutes and 1.4 (IQR 1.8) hours respectively, for living donors whereas the WIT and CIT for deceased donor grafts were 51.5 (IQR: 23) minutes and 13.9 (IQR: 5.5) hours, respectively. Excluding

TABLE 3 Recipient demographics

Characteristics	(n = 239)
Age (years), median (IQR)	48 (16)
Female sex, n (%)	103 (43.1%)
Ethnicity and race, n (%)	
African-American	127 (53.1%)
Hispanic	59 (24.7%)
Non-Hispanic White	49 (20.5%)
Other/Unknown	4 (1.7%)
BMI (kg/m^2), median (IQR)	41.4 (9.9)
BMI < 30	7 (2.9%)
BMI 30-39.9	93 (38.9%)
BMI 40-49.9	109 (45.6%)
BMI > 50	30 (12.5%)
Weight (kg), median (IQR)	119 (33.4)
ESRD Cause, n (%)	
Diabetes	20 (8.4%)
Hypertension	87 (36.4%)
Diabetes and hypertension	83 (34.7%)
Glomerulonephropathies	28 (11.7%)
PCKD	5 (2.1%)
Other	16 (6.7%)
Dialysis, n (%)	189 (79.1%)
Duration on dialysis pretransplant (months); median (IQR)	44.6 (71.1)
History of: n (%)	
Diabetes	112 (46.9%)
Hypertension	217 (90.8%)
Heart disease	49 (20.5%)
Kidney retransplant	19 (7.9%)
ABO-incompatible organ recipient	8 (3.3%)
Crossmatch-positive organ recipient	22 (9.2%)
Laboratory values, median (IQR)	
Creatinine (mg/dL)	8.1 (4.5)
eGFR (mL min^{-1} 1.73(m^2)$^{-1}$)	7.1 (3.8)
Blood glucose (mg/dL)	102 (49)
Serum albumin (g/dL)	3.8 (0.6)
WBC (1000/mm^3)	7 (3.1)

Missing values: eGFR n = 3; sCr = 1; serum albumin n = 51; WBC n = 5.
BMI, body mass index; eGFR, estimated glucose filtration rate; ESRD, end-stage renal disease; IQR, interquartile range; n = number of observations; PCKD, polycystic kidney disease; WBC, white blood cell count.

patients with normal BMI, WIT in obese patients was positively correlated with BMI (*P* = .001) (Table 4).

The graft had multiple arteries in 33 cases (13.8%), and 10 patients underwent a concomitant bariatric procedure (9 sleeve-gastrectomies and 1 laparoscopic band removal). Other nonbariatric surgeries performed at the time of transplant were 14 hernia repairs, 4 pancreatic transplants, 3 splenectomies (for ABO incompatibility), 1 native nephrectomy (for < 1 cm T1 papillary renal cell carcinoma), 1 salpingo-oophorectomy (for a benign ovarian cyst) and 1 cholecystectomy for chronic cholecystitis. There was no association between recipient BMI and the frequency of combined bariatric procedures. Increasing length of hospitalization was associated with increasing BMI (*P* = .009). Surgical details are summarized in Table 5.

Surgical complications are presented in Table 6, stratified by gender and BMI groups. Female recipients were more likely to require surgical reintervention within 30 days (10.7% vs 2.2%, *P* = .01). There were also more seromas/hematomas in female recipients (7.8% vs 0.7%, *P* = .023). The frequency of DGF was positively associated with increasing BMI (*P* = .048). Fifteen patients (6.3%) underwent reintervention within 30 days from the transplant. Of this number, 6 patients required minimally invasive reimplantation of the ureter to the bladder for urinary leak; one had arterial bleeding at the graft hilum requiring surgical reintervention and 2 required graft nephrectomy (one for hyperacute rejection on postoperative day 8 and one for vascular thrombosis on postoperative day 12). Of the 6 patients requiring ureteral reimplantation, 2 had ureteral stents placed intraoperatively (n = 159) vs 4 leaks in patients without stents (n = 80). This finding was not statistically significant (*P* = .099). Three splenectomies were necessary due to the onset of acute antibody mediated rejection refractory to medical treatment including intravenous immunoglobulin and plasmapheresis. One exploratory laparoscopy was performed to rule out a urinary leak. Another patient who underwent simultaneous pancreatic transplant required a laparoscopic washout for pancreatitis. One patient had a partial small bowel obstruction secondary to a trocar site hernia, which was reduced and repaired laparoscopically.

Other surgical complications not requiring surgical intervention were one case of SSI (0.5%) at a trocar site with associated abdominal wall cellulitis treated with local wound care and antibiotics. There were 9 other wound complications (3.8%), more than half of which were seromas or sterile hematomas.

Perioperative medical complications were one case of sepsis with associated cardiopulmonary arrest in the intensive care unit; one postoperative stroke and subsequent pulmonary embolism. Two patients developed new onset atrial fibrillation and two had pulmonary edema requiring reintubation.

Overall, the 30-day readmission rate was 37.2%, mostly for workup of an elevated creatinine in the majority of cases (17.1%). Only 10 readmissions (4.2%) were due to surgical complications and consisted of hematuria, urinary leak, and wound issues.

Twenty-seven patients (11.3%) experienced DGF overall with two of these resulting in primary nonfunction (PNF). Two living donor recipients (1.2%) developed DGF, both of whom had a prior renal transplant, and were crossmatch positive. They both received preoperative therapeutic plasmapheresis per protocol; however, one of them ultimately developed PNF. Twenty-five deceased donor recipients (34.2%) had DGF, of whom one patient developed PNF from acute cellular

TABLE 4 Organ reperfusion time and delayed graft function by BMI class

	All N = 239	BMI < 30 N = 7	BMI 30-39.9 N = 93	BMI 40-49.9 N = 109	BMI > 50 N = 30	*P*
Warm ischemia time (minutes), median (IQR)	45 (16)	50 (16)	42 (12)	48 (16)	52.5 (25)	.001
Cold ischemia time (hours), median (IQR)	2.4 (8.4)	1.8 (6.4)	1.7 (4.1)	2.7 (10)	4.1 (12.4)	.051
Deceased donor derived (hours), median (IQR)	13.9 (5.5)	10.2[a]	15.7 (7.5)	13.3 (4.8)	15 (5.8)	.380
Living donor derived (hours), median (IQR)	1.5 (1.8)	1.6 (3)	1.2 (1.4)	1.7 (1.7)	2.2 (2.7)	.155
Duration of surgery (minutes), median (IQR)	289 (86)	289 (170)	289 (75)	282 (85)	320 (97)	.193

BMI, body mass index; IQR, interquartile range.

[a]Only one patient in this category

TABLE 5 Surgical details and immunosuppression

Characteristic	(n = 239)	BMI < 30 (n = 7)	BMI 30-39.9 (n = 93)	BMI 40-49.9 (n = 109)	BMI > 50 (n = 30)	*P*
Ureteral stent, n (%)	159 (66.5%)	5 (71.4%)	54 (58.1%)	78 (71.6%)	22 (73.3%)	.177
Number of arteries, n (%)						
1	206 (86.2%)	5 (71.4%)	79 (84.9%)	97 (89%)	25 (83.3%)	.159
2	29 (12.1%)	1 (14.3%)	13 (14%)	10 (9.2%)	5 (16.7%)	
3	4 (1.7%)	1 (14.3%)	1 (1.1%)	2 (1.8%)	0	
Graft arterial reconstruction, n (%)	24 (10%)	2 (28.6%)	12 (12.9%)	8 (7.5%)	3 (10%)	.258
Estimated blood loss (mL), median (IQR)	100 (100)	70 (155)	100 (100)	100 (73)	100 (63)	.413
Length of surgery (hours), median (IQR)	4.8 (1.4)	5.3 (2.8)	4.8 (1.2)	4.6 (1.4)	5.3 (1.6)	.219
Co-surgery, n (%)						
Hernia repair	14 (5.9%)	0	7 (7.5%)	4 (3.7%)	3 (10%)	.426
Bariatric procedure	9 (3.8%)	0	2 (2.2%)	6 (5.5%)	1 (3.3%)	.600
Pancreatic transplant	4 (1.7%)	2 (28.6%)	1 (1.1%)	1 (0.9%)	0	<.001
Splenectomy	3 (1.3%)	0	2 (2.2%)	1 (0.9%)	0	.760
Other[a]	4 (1.7%)	0	2 (2.2%)	2 (1.8%)	0	.855
Length of stay (days), median (IQR)	5 (3)	4 (2)	5 (3)	6 (4)	6 (6)	.009
Induction therapy, n (%)						
Thymoglobulin	152 (63.6%)	2 (28.6%)	57 (61.3%)	70 (64.2%)	23 (76.7%)	.104
Basiliximab	69 (28.9%)	3 (42.9%)	33 (35.5%)	30 (27.5%)	3 (10%)	.047
Alemtuzimab	12 (5%)	1 (14.3%)	1 (1.1%)	6 (5.5%)	4 (13.3%)	.034
Other	14 (5.9%)	1 (14.3%)	5 (5.4%)	8 (7.3%)	0	.356
Maintenance immunosuppression, n (%)						
Tacrolimus	218 (91.2%)	6 (85.7%)	83 (89.2%)	99 (90.8%)	30 (100%)	.305
Cyclosporine	13 (5.4%)	1 (14.3%)	5 (5.4%)	7 (6.4%)	0	.392
Mycophenolate	237 (99.2%)	7 (100%)	92 (98.9%)	108 (99.1%)	30 (100%)	.943
Other	12 (5%)	0	7 (7.5%)	5 (4.6%)	0	.358

BMI, body mass index; n, number of observations; IQR, interquartile range; SD, standard deviation.

[a]Other cases: 1 cholecystectomy, 1 salpingo-oophorectomy, 1 appendectomy, and 1 native nephrectomy. Missing values: estimated blood loss n = 6, Arterial reconstruction = 2

rejection (biopsy-proven Banff 2A). Overall, graft rejection was reported in 48 patients (20.1%). During the study period, 17 graft losses (7.1%) were recorded, including the 2 PNF cases. Only 4 graft losses occurred during the first 12 months after transplantation (2 PNF, 1 graft arterial thrombosis, and 1 hyperacute rejection). The main cause of graft failure was rejection (10 patients), followed by noncompliance to the immunosuppressive therapy (3 patients), BK virus nephropathy (2 patients), one graft arterial thrombosis and one torsion of the transplanted kidney, which occurred during the postoperative course of a pancreas-after-kidney transplant (Table 7). Median creatinine at 1 month was 1.7 (IQR: 0.86, range: 0.8-14.3) mg/dL and down to 1.4 (IQR: 0.66, range: 0.6-5.5) mg/dL by 1 year. The mean eGFR at 1 month

TABLE 6 Complications stratified by gender and BMI class

Outcome/intervention	N = 239 n (%)	Female (N = 103)	Male (N = 136)	*P*	BMI < 30 (n = 7)	BMI 30-39.9 (n = 93)	BMI 40-49.9 (n = 109)	BMI > 50 (n = 30)	*P*
Surgical complications									
Reoperation within 30 d	15 (6.3%)	11 (10.7%)	4 (2.9%)	.028	0	8 (8.6%)	6 (5.5%)	1 (3.3%)	.610
Splenectomy	3 (1.3%)	3 (2.9%)	0	.079	0	0	3 (2.8%)	0	.305
Graft removal	2 (0.8%)	1 (1%)	1 (0.7%)	1.000	0	2 (2.2%)	0	0	.367
Urinary leak – laparoscopic reimplantation	6 (2.5%)	4 (3.9%)	2 (1.5%)	.407	0	4 (4.3%)	2 (1.8%)	0	.505
Negative exploratory laparoscopy for possible urinary leak	1 (0.4%)	1 (1%)	0	.431	0	0	1 (0.9%)	0	.754
Port site hernia – laparoscopic reduction/repair	1 (0.4%)	1 (1%)	0	.431	0	0	0	1 (3.3%)	.072
Laparoscopic washout for pancreatitis (SPK patient)	1 (0.4%)	1 (1%)	0	.431	0	1 (1.1%)	0	0	.665
Bleeding	1 (0.4%)	1 (1%)	0	.431	0	1 (1.1%)	0	0	.665
Wound complications	9 (3.8%)	0	1 (0.7%)	1.000	0	2 (2.2%)	4 (3.7%)	3 (10%)	.244
Surgical site infections	1 (0.4%)	1 (1%)	0	.431	0	1 (1.1%)	0	0	.665
Cellulitis	1 (0.4%)	1	0	.431	0	1 (1.1%)	0	0	.665
Seroma or hematoma	8 (3.3%)	7 (6.8%)	1 (0.7%)	.023	0	2 (2.2%)	4 (3.7%)	2 (6.7%)	.635
Prolonged wound drainage	1 (0.4%)	1	0	.431	0	0	0	1 (3.3%)	.072
Urinary complications	12 (5%)	7 (6.8%)	5 (3.7%)	.215	0	4 (4.3%)	7 (6.4%)	1 (3.3%)	.785
Nonoperative management	6 (2.5%)	3 (2.9%)	3 (2.2%)	1.000	0	1 (1.1%)	4 (3.7%)	1 (3.3%)	.533
Reimplantation	6 (2.5%)	4 (3.9%)	2 (1.5%)	.407	0	4 (4.3%)	2 (1.8%)	0	.505
Vascular complications	1 (0.4%)	0	1 (0.7%)	1.000	0	1 (1.1%)	0	0	.665
Arterial thrombosis	1 (0.4%)	0	1 (0.7%)	1.000	0	1 (1.1%)	0	0	.665
Perioperative complications									
Cerebrovascular accident	1 (0.4%)	1	0	.431	0	0	1 (0.9%)	0	.756
Pulmonary edema	2 (0.8%)	1 (1%)	1 (0.7%)	1.000	0	1 (1.1%)	0	1 (3.3%)	.332
Pulmonary embolism	1 (0.4%)	1	0	.431	0	0	1 (0.9%)	0	.756
Atrial fibrillation	2 (0.8%)	2 (1.9%)	0	.185	0	0	1 (0.9%)	1 (3.3%)	.359
Cardiac arrest	1 (0.4%)	0	1 (0.7%)	1.000	0	1 (1.1%)	0	0	.667
Incisional hernia	20 (8.4%)	9 (8.7%)	11 (8.1%)	1.000	0	10 (10.8%)	7 (6.4%)	3 (10%)	.578
Delayed graft function	27 (11.3%)	9 (8.7%)	22 (16.2%)	.119	0	5 (5.4%)	16 (14.7%)	6 (20%)	.048
Readmission within 30 d	89 (37.2%)	44 (42.7%)	45 (33.1%)	.139	1 (14.3%)	36 (38.7%)	42 (38.5%)	10 (33.3%)	.585
Elevated creatinine	36 (15.1%)	18 (17.5%)	18 (13.2%)	.369	1 (14.3%)	13 (14%)	16 (14.7%)	6 (20%)	.889
Abdominal pain	6 (2.5%)	5 (4.9%)	1 (0.7%)	.087	0	4 (4.3%)	2 (1.8%)	0	.498
Surgical complication	7 (2.9%)	5 (4.9%)	2 (1.5%)	.144	0	3 (3.2%)	4 (3.7%)	0	.716
Urinary tract infection	7 (2.9%)	4 (3.9%)	3 (2.2%)	.468	0	4 (4.3%)	1 (0.9%)	2 (6.7%)	.278
Other[a]	33 (13.8%)	12 (11.7%)	21 (15.4%)	.453	0	12 (12.9%)	19 (17.4%)	2 (6.7%)	.299

n, number of observations; SPK, simultaneous pancreas-kidney.

[a]Other infections, hyperglycemia, gastroesophageal reflux disease, gastrointestinal bleeding, dyspnea.

and 1 year was 43.9 ± 15.7 and 56.5 ± 17.3 mL/min/1.73 m^2, respectively (Figure 1A,B).

During follow-up, 21 patients (8.8%) developed an incisional hernia, all of which were repaired laparoscopically. The median follow-up was 25.9 (35.7) months. Eleven patients died (1 suicide, 4 sepsis, 1 cardiac failure, and 5 patients for unknown reasons). As shown in the Kaplan-Meier curves, graft survival at 1 and 3 years was 98% and 93% respectively (Figure 2A).

TABLE 7 Graft and patient outcomes stratified by BMI class

Outcomes	N (%)	BMI < 30 (n = 7)	BMI 30-39.9 (n = 93)	BMI 40-49.9 (n = 109)	BMI > 50 (n = 30)	*P*
Rejection, n (%)	48 (20.1%)	0	20 (21.5%)	21 (19.3%)	7 (24.1%)	.530
Biopsy proven	42 (17.6%)	0	17 (18.3%)	18 (16.5%)	7 (24.1%)	.482
Humoral rejection	24 (10%)	0	8 (8.6%)	10 (9.2%)	6 (20.7%)	.195
Acute cellular rejection	27 (11.3%)	0	14 (15.1%)	11 (10.1%)	2 (6.7%)	.406
Multiple episodes of rejection, n (%)	12 (5%)	0	6 (6.5%)	6 (5.5%)	0	.504
Hospital admissions for infection, n (%)[a]	69 (28.9%)	2 (28.6%)	26 (28%)	31 (28.4%)	10 (34.5%)	.921
Posttransplant onset of: n(%)						
Diabetes	17 (7.1%)	0	3 (3.2%)	11 (10.1%)	3 (10.3%)	.206
Hypertension, n (%)	5 (2.1%)	0	1 (1.1%)	1 (0.9%)	3 (10.3%)	.012
Coronary heart disease, n (%)	6 (2.5%)	0	1 (1.1%)	4 (3.7%)	1 (3.4%)	.646
Deep vein thrombosis, n (%)	15 (6.3%)	0	4 (4.3%)	9 (8.3%)	2 (6.7%)	.610
Graft loss, n (%)	17 (7.1%)	0	8 (8.6%)	7 (6.4%)	2 (6.7%)	.819
Rejection	10 (4.2%)	0	3 (3.2%)	5 (4.6%)	2 (6.7%)	.779
BK nephropathy	2 (0.8%)	0	1 (1.1%)	1 (0.9%)	0	.945
Noncompliance	3 (1.2%)	0	3 (3.2%)	0	0	.192
Other[b]	2 (0.8%)	0	1 (1.1%)	1 (0.9%)	0	.945
Death, n (%)	11 (4.6%)	0	6 (6.5%)	2 (1.8%)	3 (10.3%)	.163
Length of follow-up (month), median (IQR)	25.9 (35.7)	10.2 (52.5)	29.1 (34)	26.4 (37.5)	13.8 (21.3)	.055

BMI, body mass index; n, number of observations; IQR, interquartile range.

Missing values: onset of diabetes n = 3; onset of hypertension n = 1; onset of deep vein thrombosis n = 1.

[a]Urinary tract infection (40), Clostridium difficile infection (12), pneumonia or viral infections (10), acute pyelonephritis (6), cytomegalovirus viremia/colitis (4). cellulitis (5), central line infection (1), hepatitis B (1), appendicitis (1) and sepsis (1); mortalities: 1 from decompensated congestive heart failure, 4 from sepsis, 1 suicide, 5 unknown etiology.

[b]Other: heel ulcer, CMV gastritis.

Patient survival at 1 and 3 years was 98% and 95% respectively (Figure 2B). Graft and patient survival were comparable to UNOS patients transplanted over the same time period stratified by donor type (Figure 3A,B).

Technically speaking, our approach is not difficult to master. The median WIT for our group is 45 minutes. A plot of surgeon case volume versus WIT is presented in Figure 4. Overall, our surgeons are able to reach this level of proficiency by the 20th procedure. It is

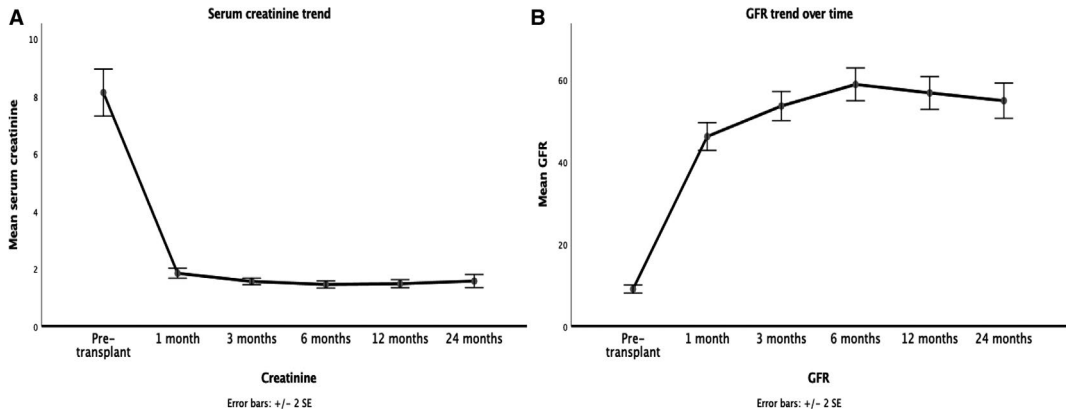
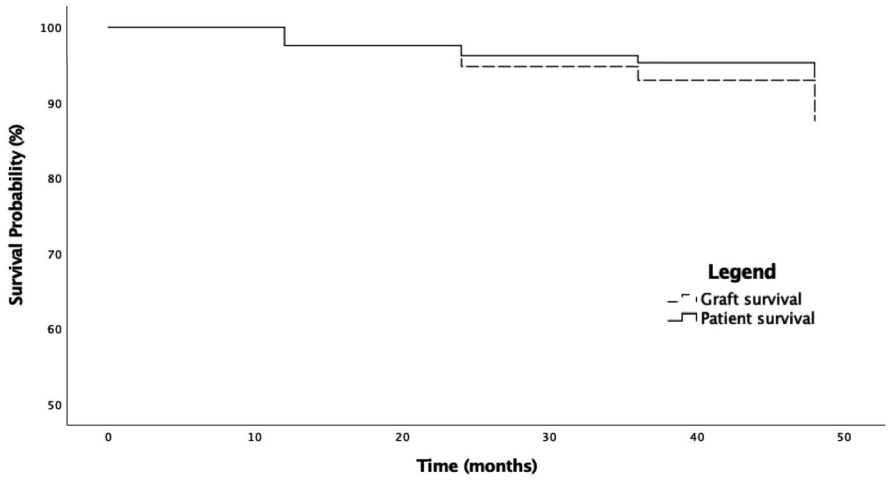
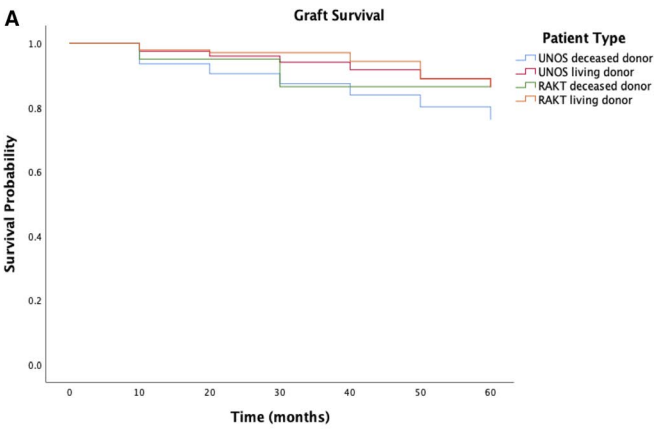


FIGURE 1 Serum creatinine and glomerular filtration rates trend during study period. (A) Mean serum creatinine and standard error of mean over scheduled time points. $P < .001$ estimated using repeated measures analysis of variance. (B) Mean glomerular filtration rate and standard error of mean over scheduled time points. $P < .001$ estimated using repeated measures analysis of variance

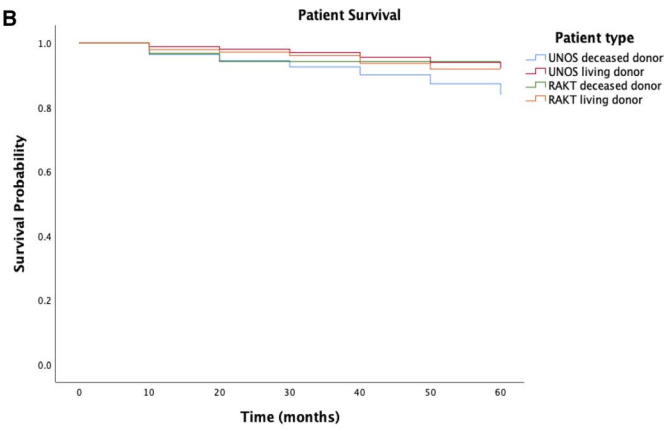


Kaplan-Meier plot comparing patient and graft survival

FIGURE 2 Overall graft and patient survival. The Kaplan-Meier graft survival and patient survival plots for robotic-assisted kidney transplant patients are depicted below. The graft survival at 1 and 3 years was 98% and 93% respectively. The patient survival at 1 and 3 yrs was 98% and 95% respectively



Estimated Survival		
	1 year	3 years
UNOS deceased donor	93%	85%
UNOS living donor	97%	93%
Robotic deceased donor	97%	94%
Robotic living donor	98%	93%



Estimated Survival		
	1 year	3 years
UNOS deceased donor	96%	91%
UNOS living donor	99%	96%
Robotic deceased donor	97%	94%
Robotic living donor	98%	96%

FIGURE 3 (A) The Kaplan-Meier graft survival curves for robotic-assisted kidney transplant patients compared to UNOS patients over the same period stratified by donor type are depicted below. Graft survival at 1 and 3 years are Deceased donor UNOS patients 93%, 85%; Living donor UNOS patients 97%, 93%; Deceased donor robotic patients 97%, 94%; Living donor robotic patients 98%, 93%. (B) The Kaplan-Meier patient survival curves for robotic-assisted kidney transplant patients compared to UNOS patients over the same period stratified by donor type are depicted below. Patient survival at 1 and 3 years are Deceased donor UNOS patients 96%, 91%; Living donor UNOS patients 99%, 96%; Deceased donor robotic patients 97%, 94%; Living donor robotic patients 98%, 96%

important to note that not every surgeon has the same dexterity and exposure to robotic surgery, as the individual surgeon metrics demonstrate (Figure 4B).

4 | DISCUSSION

This study demonstrates promising outcomes of 10 years of experience performing RAKT in an obese patient population (BMI > 30 kg/m^2). To our knowledge, this is the largest cohort to date of robotic kidney transplants. Wound complications were minimal, and only one patient developed SSI. Although, the median WIT was greater than 40 minutes, few patients experienced DGF or graft loss. Graft loss was mostly attributed to acute rejection, patient noncompliance, and BK virus nephropathy. Transplant function and recipient survival were optimal and comparable to the UNOS population from the same period of time.

Despite an increasing prevalence of obesity, many transplant centers do not list obese candidates. Segev et al analyzed UNOS data and showed that 21% of transplant centers do not list morbidly obese patients, which may be an underestimation.[7] Additionally, once listed, the median time to transplantation is greater than 50 months for patients with a BMI ≥ 35 kg/m^2 in comparison to 40 months for nonobese patients (P < .001). BMI at 1 year

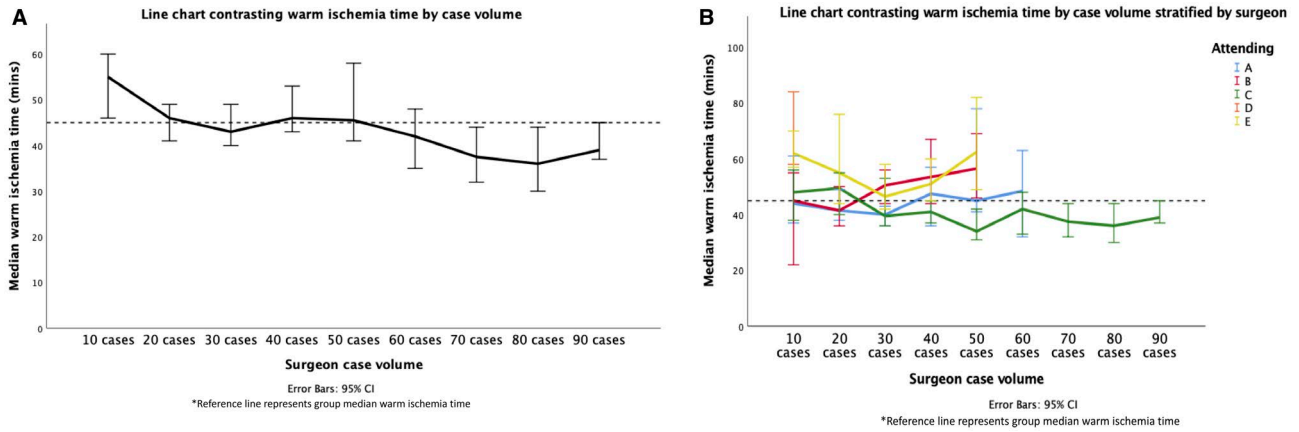


FIGURE 4 (A) Line chart contrasting warm ischemia time by case volume. Surgeons in the group attain median warm ischemia time by 20th case. (B) Line chart contrasting warm ischemia time by case volume stratified by surgeon. Surgeons A and C with case volumes > 50 have consistently lower warm ischemia times compared to the others in the group

posttransplant or an increase in BMI by 5kg/m^2 showed a stronger association with death (hazard ratio [HR] 1.39, CI 1.05-1.86; HR 1.23, CI 1.01-1.50, respectively) than pretransplant obesity.[8] These results further shift the paradigm from not transplanting high BMI patients but rather focusing on posttransplant nutrition and weight loss because transplantation is beneficial regardless of pretransplant BMI.[9]

Glanton's review of 7443 patients waitlisted for transplantation with a BMI > 30 kg/m^2 from the United States Renal Data System revealed a 50% reduction in mortality risk (3.3 vs 6.6 deaths/100 patient-years) with transplantation.[10] This finding highlights the benefits of transplantation in obese patients and emphasizes the need to provide equal opportunity to these patients.

To improve access, surgical interventions and perioperative care must address the increased risk of deep vein thrombosis (DVT) and wound complications (superficial and deep infections, dehiscence and fluid collections, delayed wound healing, incisional hernias) seen in obese individuals.[11] Lynch and colleagues showed that a BMI ≥ 30 kg/m^2 placed patients at increased risk of an SSI (HR 2.2) and concurrently, graft loss was associated with SSI (HR 2.2).[12] This was further supported by work in the early 2000s demonstrating that obese transplant candidates have prolonged operative time, increased incidence of wound infections, and longer hospital admissions compared with nonobese patients.[13-15]

Minimally invasive surgery can help in minimizing the risk of wound complications in obese patients, where the operative field is deep, narrow, and dexterity is of paramount importance. In fact, wound complication rates from RAKT are significantly lower compared to the traditional open kidney transplants (3.6% vs 28.6%, $P = .02$).[6]

In our series, the robotic technique utilized a minimally invasive approach, resulting in an SSI rate of 0.4%. With morbidly obese (BMI > 40kg/m^2) patients receiving most of their transplants robotically and our group having more than half the American experience in transplanting these high BMI patients, our outcomes and result support the utility of this technology.[16] Other relevant factors necessary in lowering wound complication rates include good surgical technique and appropriate skin preparation.

There are, however, studies that report a negative impact of obesity on graft and patient survival. Meier-Kriesche et al found that recipients with a BMI > 36 kg/m^2 had a 50% higher adjusted relative risk of graft loss when compared to nonobese patients.[17] An analysis of the Netherlands Organ Transplant Registry showed statistically different graft and patient survival for obese versus their nonobese counterparts at 1 year (graft: 86% vs 92%; patient: 88% vs 94%, $P < .01$).[18] These findings have been refuted. Furriel et al compared different BMI groups (normal weight vs overweight vs obese patients) and showed that the rate of graft loss (10.2 vs 8.7% vs 7.7%), patient survival at 1 year (97.2 vs 98.4% vs 100%) and graft survival at 1 year (98.3 vs 99.2% vs 96.2%) were comparable among all cohorts.[19] The present study on obese/morbidly obese candidates confirmed those patient and graft survival results.

Prolonged WIT is known to be a negative predictor for postoperative creatinine levels, DGF, and overall graft survival.[20,21] WIT has also been demonstrated to be longer in obese patients (38 vs 31 minutes, $P < .001$).[12] At the same time, longer WIT is common in minimally invasive transplant procedures.[22,23] Even with our average WIT approaching 50 minutes, we report a relatively low incidence of DGF in our cohort. We implemented simple maneuvers like reducing the pneumoperitoneum after reperfusion of the graft, utilizing suture of predefined length and with the corner knot already tied, and meticulous benching of the kidney to prevent any oozing at the reperfusion to potentially reduce WIT and DGF incidence.[14]

A higher incidence of acute rejection has been reported in higher BMI patients.[15,24,25] This finding was questioned by Orlic et al, who did not find an association between recipients' BMI and the risk of acute rejection.[26] In the present study, the overall rejection rate was 20.1% and, in most cases, successfully treated medically. In 8 patients, however, acute rejection led to graft loss.

The study limitations include the retrospective design, and relatively low population of patients in certain BMI groups. Survival

comparisons to external populations utilized UNOS data as a reference, without making adjustments for population differences. Technical challenges faced over the years remain vascular in nature, as we are unable to perform this procedure in patients with severe iliac atherosclerosis. Other concerns are the prolonged WITs associated with this technique, which may account for our elevated DGF, especially in the deceased donor subgroup. The increased WITs in patients with normal BMI may suggest that this procedure is not ideal for nonobese patients. Overall, our mortality was low (4.6%) and despite the absence of statistical significance, it is important to note that almost a third of these deaths occurred in patients with a BMI > 50.

As the candidate pool continues to grow more obese, it is important that the transplant community employs strategies to improve their access to transplantation. Our results show that patients with elevated BMIs have excellent graft and patient outcomes. By implementing RAKT, we mitigate obesity-associated morbidity and show similar patient outcomes to nonobese patients transplanted with the open technique. RAKT gives the opportunity to a disadvantaged group of patients with ESRD to have more access to transplantation and to reap the benefits of this life saving procedure.[2] Their quality of life improves with transplantation and our group has shown an innovative way to apply a growing surgical technique to solve a problem of access to health care.

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DISCLOSURES

The authors of this manuscript have no conflicts of interest to disclose as described by the *American Journal of Transplantation*.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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