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Research Article

RETROSPECTIVE COMPARISON OF DELAYED GRAFT FUNCTION AND EARLY OUTCOMES AFTER ROBOT-ASSISTED VERSUS OPEN KIDNEY TRANSPLANTATION: A BIOPSY-CORRELATED SINGLE-CENTRE STUDY

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Abstract: ***Introduction:*** Robot-assisted kidney transplantation (RAKT) has emerged as a minimally invasive alternative to conventional open kidney transplantation (OKT), with potential advantages in wound morbidity, postoperative pain and recovery. Whether the robotic approach influences early graft dysfunction and the underlying histopathological pattern of graft injury remains uncertain. **Methods:** We performed a retrospective, double-arm observational study of renal transplant recipients treated at a tertiary transplant centre in New Delhi from 1 April 2016 to 1 April 2024. Six hundred recipients were included: 400 underwent OKT and 200 underwent RAKT. Early graft dysfunction was evaluated clinically and, where indicated, by graft biopsy. Patients with biopsy-proven graft rejection were excluded from the primary non-rejection graft-dysfunction analysis. Perioperative outcomes, biochemical graft function, postoperative pain, blood loss, complications and length of stay were compared. **Results:** Baseline age, sex, height, weight and BMI were comparable between groups. Graft dysfunction occurred in 96/400 (24%) OKT recipients and 44/200 (22%) RAKT recipients. Among these, biopsy assessment demonstrated predominantly acute tubular injury and mild interstitial oedema, without a significant difference in histopathological severity between groups. Serum creatinine was higher in the RAKT group at baseline and on postoperative days 3, 7 and 15, but the difference was not significant by day 30 or 90. RAKT was associated with lower postoperative pain scores, lower estimated blood loss (90.09 vs 160.90 mL; P<0.0001), shorter hospital stay (7.10 vs 9.01 days; P<0.0001), and fewer severe postoperative complications. Anastomotic times were longer with RAKT. **Conclusion:** In this retrospective cohort, RAKT provided favourable perioperative recovery with less blood loss, pain and hospital stay, while biopsy-correlated graft dysfunction showed no meaningful histopathological difference from OKT. The findings suggest that the surgical approach does not substantially modify the early biological pattern of graft injury, although the longer ischemic/anastomotic intervals associated with RAKT warrant continued technical optimization and prospective evaluation.

Keywords: robot-assisted kidney transplantation; open kidney transplantation; delayed graft function; acute tubular injury; renal allograft biopsy; ischemia-reperfusion injury; graft dysfunction.

INTRODUCTION

Kidney transplantation is the preferred form of renal replacement therapy for suitable patients with end-stage renal disease because it offers better survival and quality of life than long-term dialysis. The development of modern transplantation has therefore focused not only on graft immunology and organ preservation but also on reducing the morbidity associated with recipient surgery. The conventional open kidney transplant remains the established standard, but the large lower abdominal incision can contribute to postoperative pain, wound morbidity, impaired mobility and prolonged recovery. [1,2]

Minimally invasive surgery has progressively entered transplantation through laparoscopic living-donor nephrectomy and, subsequently, robotic recipient transplantation. The robotic platform provides three-dimensional magnified vision, articulated instruments, motion scaling and improved suturing ergonomics,

potentially facilitating precise vascular and ureterovesical anastomosis through a smaller incision. Early clinical reports demonstrated technical feasibility of RAKT, and subsequent standardized techniques with regional hypothermia expanded its application, particularly in obese recipients in whom wound complications after open transplantation may be problematic. [3-7]

Despite these technical advantages, kidney transplantation differs from other robotic urological procedures because the graft is particularly vulnerable to ischemia-reperfusion injury. Delayed graft function (DGF) represents a clinically important manifestation of early graft injury and is influenced by donor, recipient and graft-related factors, including ischemic exposure, organ quality, preservation and perioperative management. Histologically, ischemic tubular injury is a major substrate of early graft dysfunction, while acute rejection must be distinguished because it has different therapeutic implications. [8-10]

An important unresolved question is whether the longer vascular and rewarming intervals that may accompany RAKT adversely affect early graft function. Vascular anastomosis time has been associated with DGF and prolonged hospitalization, while contemporary comparative studies generally report longer warm or rewarming times with RAKT but similar rates of DGF and mid-term graft function. [11-14] Conversely, the minimally invasive approach has repeatedly been associated with lower blood loss, less postoperative pain, fewer wound complications and faster recovery. [12-16] Although several comparative studies and meta-analyses have evaluated clinical outcomes after RAKT and OKT, biopsy-correlated comparison of early graft dysfunction remains limited. Histopathological evaluation can help determine whether postoperative graft dysfunction reflects ischemic tubular injury, interstitial inflammation or acute rejection rather than simply attributing creatinine elevation to the surgical approach. The present study therefore compares RAKT with conventional OKT with particular emphasis on early graft dysfunction and its biopsy findings, while also evaluating perioperative and early functional outcomes.

AIM AND OBJECTIVES

Aim: To retrospectively compare delayed graft function/early graft dysfunction after RAKT and conventional OKT with histopathological correlation.

To compare surgical and perioperative outcomes between RAKT and OKT.

To compare postoperative complications, pain, blood loss and hospital stay.

To compare early graft function using serial serum creatinine measurements.

To evaluate graft biopsies performed for graft dysfunction and compare the histopathological patterns between the two surgical approaches.

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MATERIALS AND METHODS

Study design and setting: This was a retrospective double-arm observational study conducted in the Sir Ganga Ram Hospital, New Delhi. The study period was 1 April 2016 to 1 April 2024. The thesis records institutional ethics review and maintenance of patient confidentiality.

Study population: A total of 600 patients with end-stage renal disease who underwent renal transplantation were included. Four hundred patients underwent OKT and 200 underwent RAKT, giving a 2:1 allocation according to the available retrospective cohort. Patients with biopsy-proven graft rejection were excluded from the primary analysis of non-rejection graft dysfunction.

Data collection: Demographic characteristics, underlying renal disease, dialysis history, induction and maintenance immunosuppression, ischemia-related operative variables, serial serum creatinine, haemoglobin and tacrolimus levels, postoperative drain removal, complications, postoperative pain, estimated blood loss and duration of hospital stay were extracted from medical records using a structured proforma.

Surgical techniques: RAKT was performed using a transperitoneal robotic technique with a small midline/GelPort access incision, preparation of the external iliac vessels, graft insertion through the access incision, robotic vascular anastomosis and modified Lich-Gregoir ureterovesical anastomosis over a DJ stent. OKT was performed through a modified Gibson incision with standard extraperitoneal exposure of the iliac vessels, vascular anastomosis and ureterovesical implantation using a modified Lich-Gregoir technique.

Histopathology: Graft biopsies were obtained in patients with graft dysfunction according to clinical indication. The thesis reports assessment of acute tubular injury, interstitial oedema/inflammation, glomerular changes and rejection according to Banff-based assessment. Patients with biopsy-proven rejection were excluded from the non-rejection graft dysfunction group.

Statistical analysis: Categorical variables were compared using chi-square or Fisher exact tests and continuous variables using Student's t-test. Repeated measures of serum creatinine and tacrolimus were evaluated using repeated-measures ANOVA in the thesis dataset. A two-sided $P<0.05$ was considered statistically significant.

RESULTS

Six hundred renal transplant recipients were analysed: 400 in the OKT group and 200 in the RAKT group. The two groups were broadly comparable with respect to baseline demographic characteristics.

Variable	OKT (n=400)	RAKT (n=200)	P value
Age, years; mean±SD	40.74±12.19	40.64±14.31	0.213
Male sex, n (%)	304 (76%)	140 (70%)	0.121
Female sex, n (%)	96 (24%)	60 (30%)	
Height, cm; mean±SD	164.81±7.76	161.31±7.51	0.101
Weight, kg; mean±SD	65.31±14.20	68.60±17.90	0.119
BMI, kg/m²; mean±SD	24.11±4.80	26.60±6.32	0.061

The principal recorded causes of ESRD included diabetic nephropathy (34.6% in OKT vs 19.04% in RAKT) and hypertensive nephropathy (13.3% vs 20.6%), with other causes comprising a substantial proportion of both cohorts. Dialysis exposure was longer in the RAKT group (8.23±3.11 vs 4.03±2.51 months; P<0.0001), and weekly dialysis frequency was also higher (2.48±0.89 vs 2.00±0.39; P=0.0102).

Outcome	OKT	RAKT	P value
Warm ischemia time, min	5.00±0.92	5.39±2.10	0.0023
Cold ischemia time, min	52.5±15.6	53.73±21.47	0.119
Rewarming ischemia time, min	40.6±9.5	73.21±24.77	<0.0001
Anastomosis time, min	40.65±9.63	52.54±24.36	<0.0001
Arterial anastomosis, min	14.80±3.02	21.40±4.58	<0.0001
Venous anastomosis, min	17.30±3.10	20.01±7.12	<0.0001
Ureterovesical anastomosis, min	20.80±3.18	24.30±4.79	<0.0001

RAKT was associated with longer rewarming and anastomotic intervals. Despite this, early recovery outcomes favoured the robotic approach.

Postoperative outcome	OKT	RAKT	P value
VAS at 12 h	6.8	5.2	<0.0001
VAS at 24 h	6.1	5.0	0.0050
VAS at 48 h	5.7	4.2	0.0022
Estimated blood loss, mL; mean±SD	160.90±34.90	90.09±27.78	<0.0001
Hospital stay, days; mean±SD	9.01±1.08	7.10±1.15	<0.0001

The postoperative complication profile showed fewer grade I complications in RAKT (24 vs 51), fewer grade II complications (9 vs 18), no grade IIIa complications in RAKT versus 6 in OKT, and fewer grade IIIb complications (9 vs 21). Grade V events were also fewer in RAKT (3 vs 12). The thesis dataset identified a statistically significant difference for several complication grades.

Graft dysfunction occurred in 96/400 (24%) OKT recipients and 44/200 (22%) RAKT recipients. In the OKT cohort, 40 patients (10%) had graft rejection reported/rule-out assessment, leaving 56 patients classified as graft dysfunction in the thesis; in the RAKT cohort, 18 patients (9%) had rejection assessment, leaving 26 patients classified as graft dysfunction. Because the source thesis contains occasional numerical inconsistencies in this section, the principal manuscript analysis retains the explicitly tabulated 96 and 44 graft-dysfunction counts and reports the biopsy findings qualitatively rather than recalculating undocumented subgroup denominators.

Time after transplant	OKT creatinine (mg/dL)	RAKT creatinine (mg/dL)	P value
Day 0	2.95	4.20	<0.0001
Day 3	1.35	2.05	<0.0001
Day 7	1.18	1.76	0.0019
Day 15	1.24	1.58	0.0092
Day 21	1.26	1.57	0.0412

Day 30	1.22	1.42	0.0701
Day 90	1.28	1.33	0.1101

Within-group repeated-measures ANOVA demonstrated significant change in serum creatinine over time in both OKT ($F=158.3$, $P<0.0001$) and RAKT ($F=94.43$, $P<0.0001$) cohorts. Between groups, creatinine differences were significant through day 21 but were no longer statistically significant at day 30 and day 90.

Biopsy correlation: Graft biopsies from patients with graft dysfunction predominantly demonstrated acute tubular injury and mild interstitial oedema. The thesis reports no significant difference between RAKT and OKT in the extent or severity of tubular injury, interstitial inflammation or glomerular changes. Acute rejection findings were also comparable between groups, with no substantial difference in rejection grading. These findings suggest that early graft dysfunction was characterized by similar underlying histopathological injury in both surgical approaches.

DISCUSSION

The present study addresses an important question in contemporary kidney transplantation: whether changing the recipient operation from conventional open surgery to a robotic minimally invasive approach alters early graft injury. In 600 recipients, RAKT and OKT showed comparable baseline demographic characteristics, while RAKT was associated with significantly less postoperative pain, lower estimated blood loss and shorter hospitalization. Most importantly, the frequency of recorded graft dysfunction was similar (22% vs 24%), and biopsy examination did not demonstrate a meaningful difference in the histopathological pattern of graft injury. These findings are clinically relevant because the major concern surrounding RAKT is that additional operative and rewarming time might compromise graft function.

RAKT has evolved from isolated feasibility reports into a standardized procedure. Hoznek et al. first demonstrated the feasibility of robotic recipient transplantation, while later groups developed standardized techniques incorporating regional hypothermia and refined port placement. [3-6] The current study reflects this evolution: vascular and ureterovesical anastomoses were completed robotically, allowing the benefits of magnified vision and wristed instrumentation. The thesis cohort was not restricted to morbidly obese recipients, although obesity is one of the principal settings in which minimally invasive transplantation has been adopted because the large open incision may be particularly problematic. Contemporary systematic reviews support the technical feasibility and perioperative advantages of RAKT but emphasize that the evidence base remains predominantly observational. [12-16]

The most important finding is the absence of a clinically meaningful difference in biopsy-correlated graft dysfunction. In both groups, biopsies predominantly showed acute tubular injury and mild interstitial oedema. This is biologically plausible because ischemia-reperfusion injury is a major driver of early allograft dysfunction and can arise from donor factors, preservation, recipient hemodynamics and ischemic exposure rather than incision type alone. [8-10] The lack of a histological difference therefore suggests that the robotic approach, despite creating pneumoperitoneum and requiring a different operative sequence, did not produce a qualitatively different pattern of renal parenchymal injury in this cohort.

The similar graft-dysfunction rate is consistent with published comparative evidence. A 2020 meta-analysis of six nonrandomized controlled studies found that DGF was comparable between RAKT and OKT (RR 1.10, P=0.82), although RAKT was associated with longer rewarming and total ischemia times and a lower risk of surgical-site infection. [14] A 2023 systematic review similarly concluded that available comparative studies generally support the safety and feasibility of RAKT, while acknowledging substantial heterogeneity and the lack of randomized trials. [15] More recent propensity-matched evidence has also reported no significant difference in DGF while showing reductions in overall postoperative complications with RAKT. [16] Thus, the present biopsy findings strengthen the clinical literature by showing that comparable early functional outcomes are accompanied by broadly similar tissue-level injury.

The study also demonstrated an expected trade-off between minimally invasive recovery and operative ischemic exposure. Rewarming ischemia time was substantially longer in RAKT (73.21 vs 40.6 minutes; $P<0.0001$), and total anastomosis time was also longer (52.54 vs 40.65 minutes; $P<0.0001$). Marzouk et al. reported that prolonged vascular anastomosis time was independently associated with DGF and longer hospital stay, highlighting the importance of minimizing recipient warm ischemia. [11] Tennankore et al. likewise demonstrated the adverse association of prolonged warm ischemia with graft outcomes. [13] Despite these concerns, the present study did not demonstrate worse late early creatinine outcomes: the between-group creatinine difference diminished progressively and was not statistically significant by day 30 or day 90. This suggests that, within the technical range achieved at this experienced centre, the additional rewarming time did not translate into a persistent functional disadvantage.

The perioperative advantages of RAKT were clear. Estimated blood loss was approximately 44% lower in the robotic cohort (90.09 vs 160.90 mL), postoperative VAS scores were lower at 12, 24 and 48 hours, and hospital stay was reduced by approximately 1.9 days. These findings are consistent with the minimally invasive nature of RAKT and with prior comparative studies. In an eight-year single-centre matched experience, RAKT was associated with reductions in blood loss, pain and analgesic requirement, while long-term graft and patient survival remained comparable with OKT. [16] Meta-analyses have also consistently identified lower wound morbidity and/or blood loss as major advantages of robotic transplantation. [12,14,17]

The complication data further support this interpretation. The thesis recorded fewer grade I and IIIb complications in the robotic group, including fewer wound infections and bleeding-related events. This aligns with the experience of Oberholzer et al., who reported markedly fewer surgical-site infections in obese recipients undergoing robotic transplantation compared with open transplantation. [7] However, the robotic approach is not intrinsically free of complications. Its intraperitoneal nature may contribute to ileus, and the use of pelvic ice slush and prolonged pneumoperitoneum introduces procedure-specific considerations. Therefore, the lower wound morbidity should not be interpreted as evidence that RAKT universally eliminates postoperative complications.

Serial serum creatinine provides an important complementary perspective. Creatinine was initially higher in the RAKT group, with significant differences through day 21, but the difference was no longer significant at day 30 or day 90. Several factors could account for this pattern, including the significantly longer dialysis exposure in the RAKT group, differences in preoperative native kidney urine output, and the longer rewarming/anastomotic intervals. Because the study was retrospective and non-randomized, the surgical approach cannot be considered an independent causal determinant of the early creatinine trajectory. The convergence of creatinine by later follow-up is nevertheless reassuring and supports the biopsy finding that no persistent qualitative graft injury was attributable to the robotic approach.

The immunosuppression data also deserve consideration. Most patients received tacrolimus, mycophenolate mofetil and steroids, with antithymocyte globulin used as the predominant induction regimen. The distribution of induction agents was not identical between groups, and tacrolimus levels were higher in the robotic cohort at baseline and early follow-up. These differences represent potential confounders when interpreting graft dysfunction and rejection. The fact that the biopsy findings remained comparable despite these differences is supportive, but not definitive, evidence of equivalence between surgical approaches.

An important strength of this study is the biopsy correlation. Clinical graft dysfunction is not synonymous with ischemic DGF, because acute rejection, calcineurin inhibitor toxicity, obstruction, vascular complications and other causes may produce similar biochemical findings. By examining graft tissue, the study attempted to distinguish predominantly ischemic tubular injury from rejection. The reported similarity in acute tubular injury and interstitial changes between RAKT and OKT therefore provides a more biologically informative endpoint than serum creatinine alone.

Several limitations must be recognized. First, the retrospective and non-randomized design introduces selection bias and confounding by indication. RAKT patients may differ from OKT patients in BMI, dialysis duration, donor characteristics, surgical era, surgeon experience and perioperative management. Second, the study was conducted at a single high-volume tertiary centre, limiting generalizability to centres beginning a robotic programme. Third, biopsy was performed for clinical graft dysfunction rather than by protocol; therefore, biopsy findings cannot be interpreted as a true histological assessment of every graft. Fourth, the thesis dataset contains some inconsistencies in the narrative reporting of graft-dysfunction and estimated-blood-loss values; the present manuscript prioritizes the tabulated values and avoids unsupported recalculation. Finally, follow-up was limited to early graft function and short-term graft survival, so conclusions regarding long-term graft survival should be cautious.

Overall, the findings support a balanced interpretation of RAKT. Robotic transplantation appears to preserve early graft function while providing meaningful perioperative benefits, but it should not yet be described as superior to open transplantation with respect to graft survival or DGF. Contemporary evidence syntheses have similarly concluded that RAKT reduces incision-related morbidity and some postoperative complications but has not consistently demonstrated superiority in DGF or long-term outcomes. [14-18] The major technical priority remains reduction of warm and rewarming ischemia while preserving the minimally invasive advantages of the procedure.

CONCLUSION

In this single-centre retrospective cohort of 600 kidney transplant recipients, robot-assisted kidney transplantation was associated with lower postoperative pain, lower estimated blood loss, fewer selected postoperative complications and shorter hospital stay compared with conventional open transplantation. Although RAKT involved longer anastomotic and rewarming intervals, the overall incidence of early graft dysfunction was comparable between groups. Biopsy correlation demonstrated predominantly acute tubular injury and mild interstitial oedema in both groups without a meaningful difference in histopathological severity or rejection pattern. Serum creatinine

differences diminished over time and were no longer statistically significant by 30 and 90 days. RAKT therefore appears to be a feasible and safe minimally invasive alternative to OKT in experienced centres, but prospective multicentre studies with standardized biopsy criteria, adjustment for recipient/donor risk factors and longer follow-up are required to establish its effect on DGF and long-term graft survival.

DECLARATIONS

Ethics approval: The thesis records Institutional Ethics Committee review/approval and maintenance of participant confidentiality.

Consent: The thesis records use of approved informed consent and patient information procedures.

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Conflict of interest: No conflict of interest was specified in the thesis source.

Data availability: The underlying retrospective clinical dataset is institutionally maintained; availability should be stated according to the journal and institutional policy.

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