International Journal of Surgery 99 (2022) 106264

Contents lists available at ScienceDirect

International Journal of Surgery

journal homepage: www.elsevier.com/locate/ijsu

Review

Robot-assisted kidney transplantation as a minimally invasive approach for kidney transplant recipients: A systematic review and meta-analyses

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ARTICLE INFO

Keywords:
Kidney transplantation
Robotic surgical procedures
Postoperative complications
Surgical wound infection
Graft survival
Systematic review

ABSTRACT

Background: Robot-assisted kidney transplantation (RAKT) has emerged as an alternative for kidney transplant recipients with the potential benefits of minimally invasive surgery. The aim of this systematic review and meta-analysis is to compare the clinical outcomes of RAKT with open kidney transplantation (OKT).
Methods: MEDLINE, Embase, Web of Science and Cochrane databases were systematically searched. Baseline characteristics, intraoperative and postoperative outcomes were collected, as well as long-term renal function and data on graft and patient survival.
Results: Eleven studies were included, which compared 482 RAKT procedures with 1316 OKT procedures. RAKT was associated with lower a risk of surgical site infection (Risk ratio (RR) = 0.15, $p < 0.001$), symptomatic lymphocele (RR = 0.20, $p = 0.03$), less postoperative pain (Mean difference (MD) = -1.38 points, $p < 0.001$), smaller incision length (MD = −8.51 cm, $p < 0.001$), and shorter length of hospital stay (MD = −1.69 days, $p = 0.03$) compared with OKT. No difference was found in renal function, graft, and patient survival.
Conclusions: RAKT is a safe and feasible alternative to OKT with less surgical complications without compromising renal function, graft and patient survival.

1. Introduction

Kidney transplantation is the treatment of choice for patients with end-stage renal disease (ESRD). However, since the first successful kidney transplantation performed in 1954 [1], little has changed concerning the surgical technique. Open kidney transplantation (OKT) is generally performed through a Gibson or jockey stick incision. These incisions are associated with high rates of incisional hernias (up to 16%), abdominal wound dehiscence (4%), and surgical site infections (SSI) (up to 18.6%) [2–4]. Although minimally invasive surgery could lead to a decrease in these complications, OKT currently remains the gold standard.

SSIs are especially hazardous for kidney transplant recipients due to the use of immunosuppressive agents [5]. This is even more dangerous for obese recipients, as a higher BMI increases the risk of developing a SSI, which subsequently reduces graft survival rates(4). Therefore, preventing the occurrence of SSIs in kidney transplant recipients is extremely important.

Since the first description of the technique by Giulianotti et al. [6] in 2010, robot-assisted laparoscopic kidney transplantation (RAKT) has been implemented by several centres as an alternative for OKT. RAKT has shown to decrease SSI, however longer warm ischemia times have also been reported [7], which could potentially harm the kidney graft [8–10]. The primary aim of this study is to compare the surgical outcomes of RAKT with OKT. The secondary aim is to compare the (long-term) renal function, graft and patient survival of RAKT with OKT.

2. Methods

2.1. Search strategy

A systematic literature search of the online databases MEDLINE, Embase, Web of Science and Cochrane was performed with the assistance of a medical librarian. All studies published between the 1st of January 2009 and the 10th of June 2021 were included in the search. The main keywords were ''kidney'', ''transplantation'' and ''robotic''. The full search strategy is displayed in Appendix A (Supplementary). Cross references were checked to assess if any relevant studies had been missed.

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https://doi.org/10.1016/j.ijsu.2022.106264
Received 15 August 2021; Received in revised form 23 November 2021; Accepted 9 February 2022
Available online 17 February 2022

Abbreviations

ATG	Anti-thymocyte globulin
CI	Confidence Interval
DBD	Donation after brain death
DCD	Donation after Circulatory Death
DGF	Delayed graft function
eGFR	estimated Glomerular Filtration Rate
GRADE	Grading of Recommendations Assessment Development and Evaluation
IQR	Interquartile Range
MD	Mean Difference
MMF	Mycophenolate Mofetil
OKT	Open Kidney Transplantation
SD	Standard Deviation
SSI	Surgical Site Infection
RAKT	Robot-assisted Kidney Transplantation
RR	Risk Ratio
ROBINS-I	Risk of Bias in Non-randomized Studies of Interventions
VAS	Visual Analogue Scale

2.2. Study selection

A specific population (P), intervention (I), compare (C), outcome (O) and study design (S) (PICOS) framework was used for study eligibility assessment. The PICOS framework was specified as: P: kidney transplant recipients, receiving either a living or deceased donor kidney; I: RAKT, a minimally invasive technique for kidney transplantation using a surgical robot; C: OKT, the current gold standard operating technique for kidney transplantation; O: harms and benefits of RAKT versus OKT, including peri- and post-operative surgical outcomes, (long-term) renal function, graft and patient survival; S: randomised and non-randomised studies. This systematic review was registered in Research Registry. All articles were screened on title and abstract by two independent researchers (J.S.S. and L.O.). Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) and Assessing the Methodological Quality of Systematic Reviews (AMSTAR) guidelines were followed (Fig. S1/S4/S5) [11,12]. After selection based on title and abstract, the full text manuscripts of the remaining articles were assessed. Studies were included if they fitted within the PICOS framework. Exclusion criteria were case-reports, conference/meeting abstracts, studies reporting on children/animals, case series without a OKT control group, (systematic) reviews, letters to the editor, comments and studies including kidney transplantation combined with another surgical procedure. In case of disagreements, a third independent expert party (R.C.M.) was consulted.

2.3. Outcomes

Data extraction was completed by two independent authors (J.S.S. and L.O.). Data was retrieved on the following outcomes: study design, size, recipient age, gender, BMI, type of donor, time on dialysis and immunosuppressant regimen. Data extracted for the meta-analysis comparing RAKT to OKT comprised total operative time, cold ischemia time (CIT), warm ischemia time/rewarming ischemia time, blood loss, incisional length, SSI, incisional hernia, (symptomatic) lymphocele occurrence, length of hospital stay, post-operative pain, delayed graft function (DGF), acute rejection, costs, renal function and graft and patient survival. Rewarming time in RAKT was defined as the time elapsed between placing the kidney graft into the peritoneal cavity and reperfusion of the kidney after vascular anastomoses. DGF was defined as the need for dialysis within the first week post-transplantation. Symptomatic lymphocele was defined as a lymphocele needing an intervention. Additionally, data on the complications following RAKT and the different incisions for RAKT were collected.

2.4. Quality assessment

The quality of the included articles was assessed using a modified version of the Newcastle-Ottawa Scale(NOS) [13] for cohort studies (Table S2). A maximum of nine points could be obtained. Studies graded 6–9 points were deemed of good quality, 4–5 points of moderate quality and 0–3 points of poor quality. The quality of all studies was assessed and scored by two researchers independently (J.S.S. and L.O.). Possible publication bias was assessed by visual inspection of funnel plots. The ROBINS-I tool was used to assess for risk of bias [14]. Additionally, the GRADE [15] was used to grade the overall quality of the evidence for the seven most critical outcomes (SSI, (symptomatic) lymphocele occurrence, incision length, hospital stay, post-operative pain, DGF and renal function), which were selected by two researchers (J.S.S and R.C.M.).

2.5. Statistical analysis

Data included in the meta-analysis is presented as means and standard deviations (SD). If the included article reported outcomes in medians and interquartile ranges (IQR), the method described by Wan et al. [16] was used to calculate the mean and SD.

Regarding the meta-analysis, pooled risk-ratios (RR) for dichotomous variables were calculated with 95% confidence intervals (CI) using a random effects model. The Mantel-Haenszel analysis was used with calculation of the overall effect using the Z-test. For continuous variables, the mean differences were calculated with a 95% confidence interval (CI) using random effects model, in view of the expected observational designs of included studies resulting in high between-study variance. Inverse variance analysis method was used with calculation of the overall effect using the Z-test. A p-value of less than 0.05 was considered statistically significant. Potential variance caused by heterogeneity between studies was estimated using the statistic I^2, which was defined as either low (25%), moderate (25–75%) or high (75%) heterogeneity. Contour-enhanced funnel plots were used to investigate the presence of publication bias. Review Manager 5.4 software was used to perform the meta-analysis [17].

3. Results

3.1. Included studies

The databases searches yielded 1459 citations, assessing 200 full-text articles for eligibility, which resulted in twelve studies eligible for inclusion. After in depth analysis, it was found that the data on patients included by Tugcu et al. [18] had also been reported on by Tekdos et al. [19]. It was decided to use the largest and most extensive study, which was the study by Tugcu et al. [18]. This resulted in eleven studies eligible for the qualitative analysis, which were also included in the meta-analysis. Fig. S1 outlines the full selection process.

3.2. Study characteristics

The patient population of Oberholzer et al. [7] is identical to that of Spaggiari et al. [20], however, Oberholzer et al. [7] reported on the short-term outcomes while Spaggiari et al. [20] reported on the long-term outcomes. Both studies were included to combine short and long-term results. Nine studies [7,18,20–24] were prospective cohort studies and two studies [25,26] were retrospective studies. No randomized controlled trails (RCT's) were published at the time of the search(Table 1).

Table 1
Baseline characteristics all included studies. IQR = Interquartile range, NR = Not reported, OKT = open kidney transplantation, RAKT = robot-assisted kidney transplantation, SD = Standard deviation.

Author	Year	Study Design	Study size	Sex (M/F)	Age±SD/ (IQR)	BMI±SD/(IQR)	Living/ Deceased Donor	Pre-emptive (%)	Time on Dialysis (months) ± SD/(IQR)
Oberholzer/ Spaggiari	2013/ 2018	Prospective cohort	RAKT: 28 OKT: 28	RAKT: 13/15 OKT: 11/ 17 *P = 0.59*	RAKT: 47.9 ± 10.7 OKT: 49.8 ± 10.8 *P = 0.51*	RAKT: 42.6 ± 7.8 OKT: 38.1 ± 10.8 *P = 0.02*	RAKT: 26/2 OKT: 26/2	RAKT: 19 (67.9%) OKT: 20 (71.4%) *P = 0.77*	RAKT: 32.0 ± 34.7 OKT: 15.6 ± 11.8 *P = 0.08*
Garcia-Roca	2017	Retrospective cohort	RAKT: 67 OKT: 545	RAKT: 32/35 OKT: 281/264 *P = 0.18*	RAKT: 46.4 ± 10.7 OKT: 48.1 ± 12.5 *P = 0.28*	BMI per category: *BMI < 45* RAKT: 43.2 ± 1.5 OKT: 41.6 ± 1.3 *P < 0.001* *BMI > 45* RAKT: 51.3 ± 3.6 OKT: 47.1 ± 2.0 *P < 0.001*	RAKT: living OKT: living	RAKT: 23 (34.3%) OKT: 139 (25.5%) *P = 0.083*	RAKT: 49.1 ± 38.1 OKT: 47.1 ± 43.4 *P = 0.701*
Tugcu	2018	Prospective cohort	RAKT: 40 OKT: 40	RAKT: 25/15 OKT: 28/ 12	RAKT: 37.67 ± 11.28 OKT: 42.45 ± 13.74 *P = 0.093*	RAKT: 23.2 ± 3.29 OKT: 25.3 ± 2.17 *P = 0.001*	RAKT: living OKT: living	RAKT: 15 (37.5%) OKT: 12 (30%) *P = 0.482*	RAKT: NR OKT: NR
Ahlawat	2020	Prospective cohort	RAKT: 126 OKT: 378	RAKT: 101/25 OKT: 310/68	RAKT: 40 (30–50) OKT: 41 (30–51)	BMI per category: *BMI < 18* RAKT/OKT: 8/ 58 *BMI 18-24.9* RAKT/OKT: 81/209 *BMI 25-29.9* RAKT/OKT: 27/76 *BMI > 30* RAKT/OKT: 10/35	RAKT: living OKT: living	RAKT: 27 (21.4%) OKT: 70 (18.5%)	RAKT: 2.08 (16.5–151.5) OKT: 2.12 (17–157.5)
Kishore	2020	Retrospective cohort	RAKT: 18 OKT: 18	RAKT: 13/18 OKT: 14/ 18 *P = 1.0*	RAKT: 37.1 ± 13.2 OKT: 35.2 ± 12.8 *P = 0.7536*	RAKT: 26.6 ± 3.1 OKT: 24.9 ± 3.18 *P = 0.268*	RAKT: living OKT: living	RAKT: NR OKT: NR	RAKT: NR OKT: NR
Maheshwari	2020	Prospective cohort	RAKT: 55 OKT: 152	RAKT: 42/13 OKT: 122/30 *P = 0.5422*	RAKT: 40.7 ± 13.9 OKT: 42.55 ± 11.97 *P = 0.7817*	RAKT: 26.2 ± 6.9 OKT: 24.35 ± 5.0 *P = 0.066*	RAKT: living OKT: living	NR	RAKT: 10.77 ± 8.42 OKT: 3.85 ± 3.56 *P = < 0.001*
Nataraj	2020	Prospective cohort	RAKT: 43 OKT: 43	RAKT: 30/13 OKT: 27/ 16 *P = 0.2*	RAKT: 40.3 ± 13.4 OKT: 42 ± 15 *P = 0.8*	RAKT: 26.8 ± 4.2 OKT: 22.6 ± 4.4 *P = 0.05*	RAKT: living OKT: living	RAKT: 10 (23.2%) OKT: 9 (21%) *P = 0.3*	RAKT: 25 OKT: 24.17 *P = 0.9*
Pein	2020	Prospective cohort	RAKT: 21 OKT: 21	RAKT: 16/5 OKT: 10/ 11	RAKT: 48.0 ± 10.3 OKT: 44.6 ± 14.9	RAKT:25.5 ± 4.1 OKT: 26.4 ± 5.7	RAKT: living OKT: living	RAKT: 3 (21%) OKT: 2 (9.5%)	RAKT: 16.8 ± 22.8 OKT: 15.6 ± 25.22
Eksi	2021	Prospective cohort	RAKT: 60 OKT: 67	Total: 82/ 45	RAKT: 37.5 ± 10.4 OKT: 43.9 ± 11.8 *P = 0.0022*	RAKT: 23.9 ± 3.5 OKT: 24.8 ± 2.1	RAKT: living OKT: living	RAKT: 24 (40%) OKT: 20 (29.6%)	RAKT: NR OKT: NR
Lee	2021	Prospective cohort	RAKT: 24 OKT: 24	RAKT: 14/10 OKT: 9/ 15	RAKT: 51.21 ± 11.9 OKT: 56.29 ± 11.9	RAKT: 40.1 (35–49) OKT: 38.5 [35–44]	RAKT: 9/15 OKT: 6/18	RAKT: 1 (4.2%) OKT: 1 (4.2%)	RAKT: 48.1 ± 34.5 OKT: 50.7 ± 38.5

3.3. Outcomes

3.3.1. Baseline characteristics

The eleven studies included a total of 482 RAKT procedures, compared to a total of 1316 OKT procedures. This included 465 living donor kidney transplantations and 17 deceased donor kidney transplantations. Three studies had a RAKT group with a significantly higher BMI compared to the OKT group [7,23,25], and in the study by Tugcu et al. [18], the RAKT group had a significantly lower BMI [18]. The time on dialysis was significantly longer in the RAKT group in the study by Maheshwari et al. [22]. The RAKT population of the study by Ekşi et al. [27] was significantly younger than the OKT group. Other baseline characteristics did not show a statistically significant difference between the RAKT and OKT groups.

3.3.1.1. Immunosuppressant regimen. There was resemblance between immunosuppressant regimens of the included studies. Most studies reported on a regimen consisting of induction therapy with antithymocyte globulin (ATG) or basiliximab and maintenance with triple therapy (tacrolimus, MMF (mycophenolate mofetil) and a steroid). Three studies used induction with basiliximab/ATG for all patients [21,22,28], four studies gave induction only to highly immunized patients [7,18,23,27] and two studies did not specify immunosuppressant regimen [24,26]. Garcia-Roca et al. [25] showed a difference in use of prednisone between RAKT and OKT group, although this is most likely caused by the fact that this is a nationwide analysis and data of many transplant centres is included. The studies included in the analyses were published between 2013 and 2021 and no change of immunosuppressant regimen was noticed over time. Complete immunosuppressant regimens are presented in Table 2.

3.3.2. Perioperative outcomes

3.3.2.1. Total operative time. Seven studies comparing 332 RAKT with 591 OKT procedures, reported on the total operative time and provided data for the meta-analysis [18,21,23,24,26–28]. Total operative time was significantly longer in the RAKT group compared to the OKT group: mean difference (MD) = 24.28 min; 95%-CI: [4.06-44.49]; $p < 0.02$ (Table 2, Fig. S2).

3.3.2.2. Cold ischemia time. Seven studies comparing 337 RAKT with 686 OKT procedures, provided data on the cold ischemia time (CIT) for the meta-analysis [7,18,21–24,28]. CIT was significantly longer in the RAKT group: MD = 5.18 min; 95%-CI: [3.99–6.38]; $p < 0.001$ (Table 2, Fig. S3)

3.3.2.3. Rewarming time. Eight studies comparing 312 RAKT with 661 OKT procedures, reported on the second warm ischemia time or rewarming ischemia time in the recipient (ReWIT) (Table 2) [7,18,21–24,26,28]. ReWIT was longer in the RAKT group in seven studies [18,21–24,26,28], which difference was statistically significant in four studies [18,21,22,24]. The circumstances of the ReWIT are different between RAKT and OKT, due to the cooling of the kidney during RAKT. Therefore, it was decided not to conduct a meta-analysis on this subject.

3.3.2.4. Blood loss. Seven studies comparing 339 RAKT with 598 OKT procedures, provided data on intraoperative blood loss (Table 2), which were included in the meta-analysis [7,18,21,23,26–28]. Blood loss was significantly less in the RAKT group compared with the OKT group, MD = −54.74 mL; 95%-CI: [−96.60 – 12.58]; p = 0.01(Fig. S4).

3.3.2.5. Incision length. Five studies comparing 287 RAKT with 546 OKT procedures, reported on the length of the incision, which were included in the meta-analysis [18,21,23,26,27]. Incision length was significantly shorter in the RAKT group: MD = −9.13 cm; 95%-CI: [8.14–10.13]; $p < 0.001$(Fig. 1A).

3.3.3. Early postoperative outcomes

3.3.3.1. SSI. Eight studies comparing 335 RAKT with 704 OKT procedures, reported on SSI after kidney transplantation and were included in the meta-analysis (Table 3, Fig. 1B) [7,18,21–24,26,28]. The risk of developing SSI was significantly lower in the RAKT group: relative risk (RR) = 0.15; 95%-CI: [0.06–0.38]; $p < 0.001$.

3.3.3.2. Incisional hernia. Four studies reported on the occurrence of incisional hernias (Table 3). Maheshwari et al. [22] reported two incisional hernias in the RAKT group (3.6%) and zero in the OKT group (0%), this difference was not statistically significant. Three studies reported no occurrence of surgical hernias [18,21,24].

3.3.3.3. Lymphoceles. Five studies comparing 288 RAKT with 637 OKT procedures, reported on the occurrence of either symptomatic or asymptomatic lymphoceles and provided data for the meta-analysis [18,21–23,28], all of which concerned symptomatic lymphoceles. The occurrence of symptomatic lymphoceles was significantly lower in the RAKT group: RR = 0.20; 95%-CI: [0.04–0.89], p = 0.03 (Table 3, Fig. 1C). Of 31 symptomatic lymphoceles that occurred, 28 were treated with percutaneous needle aspiration and two were resolved laparoscopically. Treatment of one lymphocele was not specified.

3.3.3.4. Vascular and ureter complications. Two studies reported on a total of 10 venous graft thrombosis in the OKT group. No graft thrombosis was reported in the RAKT group. Arterial stenosis occurred in one RAKT recipient and three OKT recipients. Ureter problems were reported in three RAKT patients (two strictures, one unspecified) and two OKT patients (one leakage, one unspecified) (Table S3).

3.3.3.5. Pain scores. Five studies comparing 287 RAKT with 546 OKT procedures, reported on the pain scores after surgery at 12, 24 and 48 h using the visual analogue scale (VAS). Pain scores 24 and 48 h postoperatively were included in the meta-analysis, for which five studies provided data [18,21,23,26,27]. These were significantly lower in the RAKT group, MD was respectively −1.38 [95%-CI: 1.15–1.61] $p < 0.001$ and −0.54 [95%-CI: 0.34–0.74] $p < 0.001$ (Table 3, Fig. 2).

3.3.3.6. DGF. Ten studies comparing 482 RAKT with 1316 OKT procedures, reported on the occurrence of DGF and were eligible for inclusion in the meta-analysis [7,18,21–28]. The occurrence of DGF did not significantly differ between groups: RR = 0.99; 95%-CI: [0.63–1.54]; p = 0.95 (Table 3, Fig. 3A).

3.3.3.7. Length of hospital stay. Seven studies comparing 320 RAKT with 579 OKT procedures, reported on the length of hospital stay in days after RAKT and were eligible for meta-analysis [7,21,23,24,26–28]. The average hospital stay was significantly shorter in the RAKT group: MD = −1.69 days; 95%-CI: [0.15–3.22]; p = 0.03 (Table 3, Fig. 1D).

3.3.3.8. Acute rejection. Six studies comparing 235 RAKT with 810 OKT procedures, reported on the occurrence of acute rejection post-transplantation and were included in the meta-analysis [7,22,23,25,26,28]. There was no statistically significant difference in acute rejection between groups, RR = 1.06, 95%-CI = [0.61–1.84], p = 0.82 (Table 3, Fig. S5).

3.3.3.9. Costs per transplant. Three studies provided data on the costs for RAKT [7,21,22] (Table 3). Oberholzer et al. [7] was the only study that statistically analysed the differences in costs, with $75.118 for RAKT and $60.552 for OKT, and found significantly higher costs per transplant for the RAKT group compared to the OKT group (p = 0.02) for

Table 2
Perioperative outcome of studies included in the meta-analyses; ATG = anti-thymocyte globulin, MMF = mycophenolate mofetil, NR = Not reported, OKT = open kidney transplantation, RAKT = robot-assisted kidney transplantation.

Study ID	Incision to closure time (min), SD/(IQR)	Total console time (min), SD/(IQR)	Cold ischemic time (min), SD/(IQR)	Re-warming time (min), SD/(IQR)	Blood loss (mL), (SD/IQR)	Incision length (cm), SD/(IQR)	Type of Incision	Conversion to open (%)	Cooling method	Immuno-suppressant regimen
Oberholzer (2013)/ Spaggiari (2018)(7, 20)	NR	NR	RAKT: 168 ± 216 OKT: 120 ± 270 P = 0.48	RAKT: 47.7 ± 7.8 OKT: 49.2 ± 25.2 P = 0.77	RAKT: 110.2 ± 75.2 OKT: 120.8 ± 102.4 p = 0.69	NR	RAKT: Epigastric incision	NR	NR	Induction with ATG for patients with high immunological risk, basiliximab for low risk. Maintenance with triple therapy.
Garcia-Roca (2017)(25)	NR	NR	NR	NR	NR	NR	NR	NR	NR	Calcineurin inhibitor and antimetabolite in both groups. Maintenance with steroids more in OKT group. Induction with steroids in RAKT group.
Tugcu (2018) (18)	RAKT: 265.4 ± 46.6 OKT: 250.3 ± 41.3 P = 0.129	RAKT: 180.25 ± 35.26	RAKT: 40.47 ± 13.4 OKT: 32.8 ± 7.45 P < 0.001	RAKT: 54.7 ± 17.8 OKT: 37.3 ± 4.07 P = 0.001	RAKT: 182.3 ± 55.3 OKT: 210.8 ± 28.96 P = 0.005	RAKT: 5.11 + 0.67 OKT: 12.9 ± 1.48 P < 0.001	RAKT: Para-umbilical incision	0/40 (0%)	Gauze jacket filled with ice-slush	Triple therapy and ATG/basiliximab to patients with high immunological risk.
Ahlawat (2020)(21)	RAKT: 195 (178–215) OKT: 162.5 (142.5–187.5) P < 0.001	RAKT: 154 (139–175)	RAKT: 23.5 (19–28.5) OKT: 18 (14.6–23) P < 0.001	RAKT: 42 (39–47) OKT: 31.5 (28–34) P < 0.001	RAKT: 100 (75–150) OKT: 250 (175–300) P < 0.001	RAKT: 6.3 (5.9–6.9) OKT: 15.7 (14.9–16.3) P < 0.001	RAKT: Peri-umbilical incision	1/126 (0.8%)	Ice slush	Induction: ATG/ basiliximab and triple therapy, tacrolimus and MMF started day before surgery.
Kishore (2020)(26)	RAKT: 165 ± 22 OKT: 175 ± 33 P = 0.344	NR	NR	RAKT: 74.1 ± 16.3 OKT: 69.4 ± 15.3 p = 0.332	RAKT: 67 ± 39 OKT: 81 ± 73 p = 0.527	RAKT: 8.2 ± 0.9 OKT: 17.4 ± 2.9 P = 0.0001	RAKT: Pfannenstiel incision	1/18 (5.56%)	Gauze jacket filled with ice-slush	NR
Maheshwari (2020)(22)	NR	NR	RAKT:55.7 ± 22.49 OKT: 52.73 ± 17.71 P < 0.0001	RAKT: 71.85 ± 22.31 OKT: 45.26 ± 14.71 P = 0.0018	NR	NR	RAKT: Peri-umbilical incision (44%)/ Pfannenstiel incision (56%)	2/55 (3.64%)	Gauze jacket filled with ice-slush	Induction with ATG/basiliximab, calcineurin inhibitors.
Nataraj (2020)(23)	RAKT: 250 (210–300) OKT: 235 (190–300) P = 0.6	170 (130–200)	RAKT: 33 (25–40) OKT: 29 (18–35) p = 0.2	RAKT: 60 (50–75) OKT: 56 (48–71) P = 0.2	RAKT: 160 (70–105) OKT: 200 (90–300) P = 0.5	RAKT: 5.5 (5–7) OKT: 16 (15–18) P = 0.04	RAKT: peri-umbilical incision	0/43 (0%)	Gauze jacket filled with ice-slush	Triple therapy and ATG/basiliximab to patients with high immunological risk.
Pein (2020) (24)	RAKT: 306.1 ± 45.5 OKT: 212.2 ± 40.6 P < 0.05	233 ± 32.6	RAKT: 32.4 ± 0.7 OKT: 27.8 ± 8.2 P > 0.05	RAKT: 70.8 ± 13.1 OKT: 51.7 ± 9.9 P < 0.05	RAKT: 92 ± 55 OKT: NR	NR	RAKT: Periumbilical	0/21 (0%)	Gauze jacket filled with ice-slush	NR
Ekşi (2021) (27)	RAKT: 251 ± 42.7 OKT: 245.6 ± 47.6 *P = 0.511*	NR	NR	NR	RAKT: 172 ± 58.9 OKT:211.8 ± 27.7 *P < 0.001*	RAKT: 5 ± 0.8 OKT: 11 ± 1.4 *P < 0.001*	RAKT: Paraumbilical	NR	Gauze filled with ice-slush	Triple therapy and ATG to patients with high immunological risk.
Lee (2021) (28)	RAKT: 347.3 ± 64.2 OKT: 319.5 ± 88.5	NR	RAKT: 1009.7 ± 784.2 OKT: 1007.3 ± 888,6	RAKT: 45.4 ± 5.40 OKT: 39.9 ± 12.7	RAKT: 125 ± 55.7 OKT: 191.3 ± 55.7	NR	RAKT: epigastric incision	RAKT: 0/24 (0%)	None	Induction with ATG followed by triple therapy.

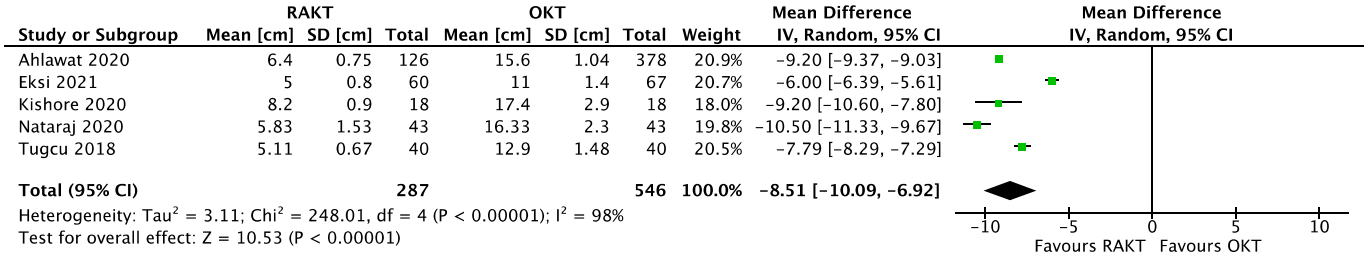


Fig. 1A. Incision length in cm.

the total hospital costs per transplant. The other two studies reported additional cost varying between $575 and $3000 [21,22]. Maheshwari et al. [22] did not report the specificity of the costs. Ahlawat et al. [21] reported an additional $575 for the GelPOINT (Applied Medical Resources, Rancho Santa Margarita, California).

3.3.3.10. Creatinine at 1-month post-transplantation. Six studies comparing 243 RAKT with 347 OKT procedures, reported the serum creatinine one-month post-operatively and provided data for the meta-analysis [18,22–24,27,28]. There was no significant difference between the serum creatinine of the RAKT and OKT groups: MD = −0.01 mg/dL; 95%-CI: [−0.22–0.20]; p = 0.90 (Table 4, Fig. S6).

3.3.4. Long term renal function

3.3.4.1. Renal function at 6-months post-transplantation. Five studies comparing 202 RAKT with 680 OKT, reported the serum creatinine six-months after kidney transplantation and were included in the meta-analysis [7,18,23,25,28]. Four studies (152 RAKT versus 630 OKT) reported data on the eGFR six-months after kidney transplantation and were included in the meta-analysis [23,25,26,28]. There was no significant difference in the serum creatinine and eGFR between groups: MD = 0.00 mg/dL; 95%-CI: [−0.09–0.08]; p = 0.80 and MD = 0.07 mL/min/1.73 cm^2; 95%-CI: [−3.25 – 3.39]; p = 0.97, respectively (Table 4, Fig. 3B).

3.3.4.2. Renal function at 1-year post-transplantation. Four studies comparing 245 RAKT with 975 OKT, reported the serum creatinine one-year post-transplantation and were included in the meta-analysis [20,21,25,28]. Three studies (119 RAKT versus 597 OKT) reported on the eGFR one-year post-transplantation and were included in the meta-analysis [20,25,28]. The meta-analysis showed a significantly lower serum creatinine in the RAKT group: MD = −0.07 mg/dL; 95%-CI: [−0.13 to −0.00]; p = 0.04 (Table 4, Fig. 2D). The meta-analysis showed no difference in eGFR in the RAKT group compared to the OKT group: MD = 0.38 mL/min/1.73 m^2; 95%-CI: [−5.78–6.53]; p = 0.90 (Table 4, Fig. 3C)

3.3.5. Graft survival

Four studies comparing 245 RAKT with 975 OKT, reported the one-year graft survival (Table S1), of which three were included in the meta-analysis [20,21,25,28]. Three studies (154 RAKT versus 406 OKT) reported on three-year graft survival and were included in the meta-analysis. No significant difference was found in death-censored graft survival at one- and three-year post-transplantation between groups: RR = 1.01; 95%-CI: [0.99–1.03]; p = 0.22 and RR = 1.05; 95%-CI: [0.90–1.23]; p = 0.53, respectively (Fig. S7A/8A). Garcia-Roca et al. [25] reported a crude one- and three-year graft survival of 95.2%/89.7% and 94.6%/90% for RAKT and OKT, respectively.

3.3.6. Patient survival

Four studies comparing 245 RAKT with 975 OKT, reported the one-year patient survival and were included in the meta-analysis [20,21,25,28]. Three studies (221 RAKT versus 951 OKT) reported on three-year patient survival. No significant difference was found in patient survival one- and three-year post-transplantation between groups: RR = 0.99; 95%-CI = 0.97–1.02; p = 0.63 and RR = 0.99; 95%-CI = 0.95–1.04; p = 0.78, respectively (Table S1, Fig. S7B/S8B).

3.4. Quality assessment

Using the modified NOS, four studies were considered of good evidence [18,21,23,28]. Six studies were considered of moderate evidence [7,20,22,25–27]. One study was considered of poor quality [24]. The quality assessment is detailed in Table S2. The ROBINS-I tool was used for assessment of bias for the studies included in the meta-analysis. Two studies were considered low risk of bias [21,23], seven studies moderate risk of bias [7,18,20,22,24,26,27] and two study serious risk of bias [25,28] (Fig. S19). The GRADE was used to assess overall quality of evidence of outcomes. The quality of outcomes SSI, symptomatic lymphocele, pain at 24-h, DGF and six-month creatinine was graded as high and the quality of the evidence for incision length and hospital stay was graded as moderate (Table S3).

3.5. Publication bias

Contour-enhanced funnel plots were used to investigate the presence of publication bias. Minimal publication bias was detected for incision length and hospital stay. No evidence of publication bias was found regarding the other outcomes (Figs. S8–S18).

4. Discussion

Our meta-analysis found lower RR's for the development of SSI, symptomatic lymphocele, shorter hospital stay, decreased post-operative pain, and a smaller incision length when comparing RAKT with OKT. No difference was found in (long-term) renal function and graft and patient survival.

Although intraoperative blood loss was also significantly lower in the RAKT group, we decided that a difference of 54 mL is not clinically relevant and should not be considered beneficial. Therefore, it should not be taken into consideration when deciding on RAKT or OKT.

These promising outcomes could especially benefit obese kidney transplant recipients. Obese patients with ESRD are often longer waitlisted for kidney transplantation and many transplant centres are hesitant to accept obese ESRD patients due to higher complication rates [29]. A higher BMI increases the risk of developing a SSI, which subsequently reduces graft survival rates [4]. However, obese patients who do not develop a SSI have the similar outcomes as non-obese patients [4]. Our meta-analysis showed that RAKT is an excellent technique to prevent the occurrence of SSIs, also in the obese population. Therefore, in the absence of contraindications, RAKT could be the preferred surgical technique for obese kidney transplant recipients, although more comparative research is needed in this population, preferably in a well-powered RCT.

Wagenaar et al. [30] published a systematic review in 2017 in which

Table 3
Early postoperative outcomes. DGF = delayed graft function, IQR = Interquartile range, NR = Not reported, OKT = Open Kidney Transplantation, RAKT = Robot assisted kidney transplantation, SD = standard deviation, SSI = Surgical site infection, USD = United States Dollars, a = creatinine in mg/dL, b = eGFR in mL/min/1.73 m2.

Study ID	Study Size	SSI	Incisional hernia	Lymphoceles, n (%)	Pain Score 12h ± SD/ (IQR)	Pain Score 24h ± SD	Pain Score 48h ± SD/ (IQR)	DGF (%)	Acute rejection (%)	Hospital Stay ± SD/(IQR) (Days)	Costs per transplant (USD)	Creatinine[a] Day 7 ± SD/(IQR)	eGFR[b] Day 7 ± SD
Oberholzer/ Spiaggari (2013/ 2018) [7,20]	RAKT: 28 OKT: 28	RAKT: 0 OKT: 8 *P = 0.004*	NR	RAKT: 0 (0%) OKT: 0 (0%)	NR	NR	NR	RAKT: 1 (3.6%) OKT: 0 *P = 0.99*	RAKT: 3 (10.7%) OKT: 3 (10.7%) *P = 0.98*	RAKT: 8.2 ± 4.5 OKT: 8.1 ± 5.3	RAKT: $75.118 OKT: $60.552 *p = 0.02*	NR	NR
Garcia-Roca (2017) (25)	RAKT: 67 OKT: 545	NR	NR	NR	NR	NR	NR	RAKT: 2 (3%) OKT: 31 (5.7%) *P = 0.504*	RAKT: 2 (3%) OKT: 10 (1.9%)	NR	NR	NR	NR
Tugcu (2018)(18)	RAKT: 40 OKT: 40	RAKT: 1 OKT: 3 *P = 0.615*	RAKT: 0 OKT: 0	RAKT: 0 (0%) OKT: 2 (5%) (symptomatic)	RAKT: 5.65 ± 1.07 OKT: 7.25 ± 0.95 *P < 0.001*	RAKT: 4.85 ± 1.21 OKT: 6.30 ± 0.93 *p < 0.001*	RAKT: 3.37 ± 1.61 OKT: 4.02 ± 1.22 *P = 0.046*	RAKT: 1 OKT: 0	NR	NR	NR	NR	NR
Ahlawat (2020)(21)	RAKT: 126 OKT: 378	RAKT: 0 OKT: 15 *P = 0.023*	RAKT: 0 OKT: 0	RAKT: 0 (0%) OKT: 26 (6.9%) (symptomatic) *P = 0.03*	RAKT: 3.7 ± 0.7 OKT: 4.6 ± 1 *P < 0.001*	RAKT: 2.2 ± 1.3 OKT: 3.5 ± 0.7 *P < 0.001*	RAKT: 1.2 ± 1.3 OKT: 1.7 ± 0.8 *P = 0.025*	RAKT: 0 OKT: 9 *P = 0.081*	NR	RAKT: 8 (5–12) OKT: 8 (6–14) *P = 0.647*	$575 additional for RAKT	NR	NR
Kishore (2020)(26)	RAKT: 18 OKT: 18	RAKT: 0 OKT: 0	NR	NR	NR	RAKT: 2.7 ± 1.3 OKT: 3.34 ± 1.7 *P = 0.27*	RAKT: 1.42 ± 0.9 OKT: 1.9 ± 0.8 *P = 0.131*	RAKT: 0 OKT: 0	RAKT: 1 OKT: 1	RAKT: 6.71 ± 1.7 OKT: 7.75 ± 2.3 *P = 0.17*	NR	NR	NR
Maheshwari (2020) (22)	RAKT: 55 OKT: 152	RAKT:0 OKT: 10	RAKT: 2 OKT: 0	RAKT: 0 (0%) OKT: 2 (1.3%) (symptomatic)	NR	NR	NR	RAKT: 5 OKT: 8	RAKT: 7 OKT: 16 *P = 0.63*	RAKT: 7 OKT: 7	$3000 additional for RAKT	RAKT: 1.75 ± 1.28 OKT: 1.17 ± 0.58 *P < 0.001*	NR
Nataraj (2020)(23)	RAKT: 43 OKT: 43	RAKT: 0 OKT: 6 *P = 0.04*	NR	RAKT: 0 (0%) OKT: 0 (0%)	RAKT: 5 OKT: 6 *P = 0.8*	RAKT: 3 OKT: 5 *P = 0.04*	RAKT: 2 OKT: 4 *P = 0.03*	RAKT: 0 OKT: 0	RAKT: 2 OKT: 3 *P = 0.8*	RAKT: 7 (5–15) OKT: 10 (7–21) *P = 0.05*	NR	NR	NR
Pein (2020)	RAKT: 21 OKT: 21	RAKT: 0 OKT: 0	RAKT: 0 OKT: 0	RAKT: 3 (14%) (2 symptomatic/ 1 asymptomatic) OKT: NR	NR	NR	NR	RAKT: 0 OKT: 1	NR	RAKT: 15 ± 4.1 open: 23.5 ± 11.7	NR	RAKT: 2.56 ± 1.93 OKT: 3.11 ± 2.13	NR
Eksi (2021)	RAKT: 60 OKT: 67	NR	NR	NR	RAKT: 6 (4–8) OKT:7(6–8) *P < 0.001*	RAKT: 4.5 ± 1.2 OKT: 6.1 ± 0.8 *P < 0.001*	RAKT: 3 (1–5) OKT: 4 (3–5) *P < 0.001*	RAKT: 2 (3.3%) OKT: 3 (4.4%) *P = 0.387*	NR	RAKT: 9.2 ± 3.1 OKT: 14.3 ± 12.2 *P = 0.002*	NR	NR	NR
Lee (2021)	RAKT: 24 OKT: 24	RAKT: 2 OKT: 10 *P = 0.006*	NR	RAKT: 0 OKT: 1 *P = 0.99*	NR	NR	NR	RAKT: 11 (45.8%) OKT: 11 (45.8%)	RAKT: 3 OKT: 4 *P = 0.99*	RAKT: 4.63 ± 1.64 OKT: 3.92± 1.18	NR	RAKT: 4.22 ± 3.55 OKT: 3.62 ± 1.91 *P = 0.48*	RAKT: 26.74 ± 18.43 OKT: 22.33 ± 16.42 *P = 0.39*

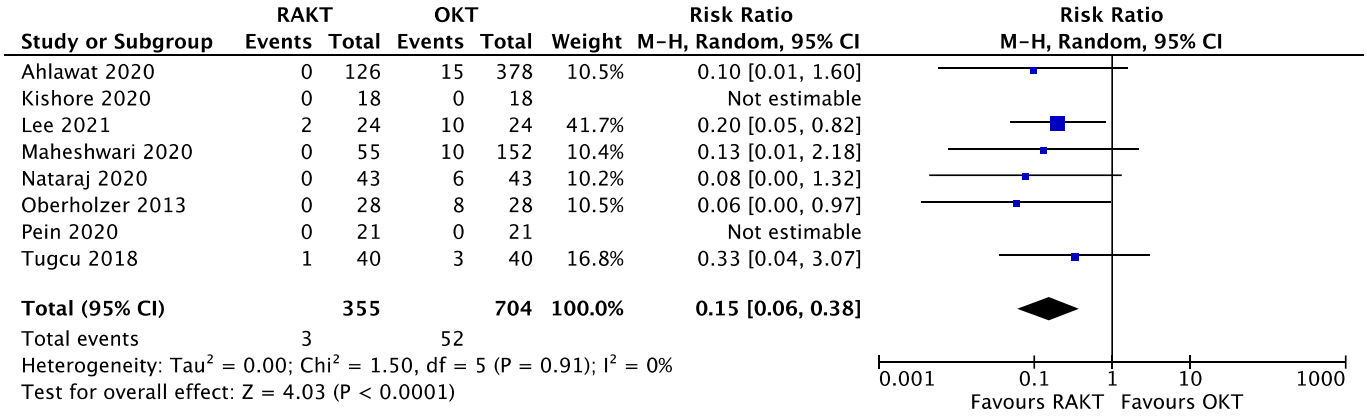


Fig. 1B. Surgical site infection.

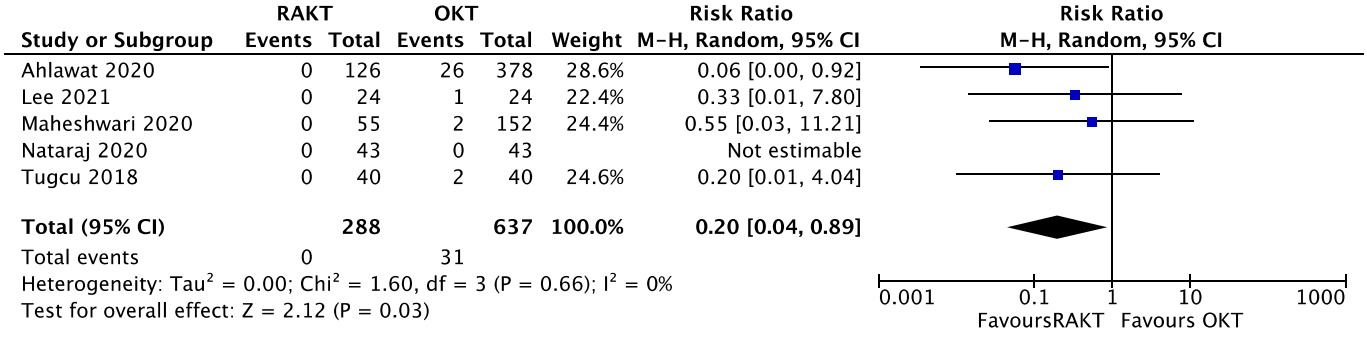


Fig. 1C. Symptomatic lymphoceles.

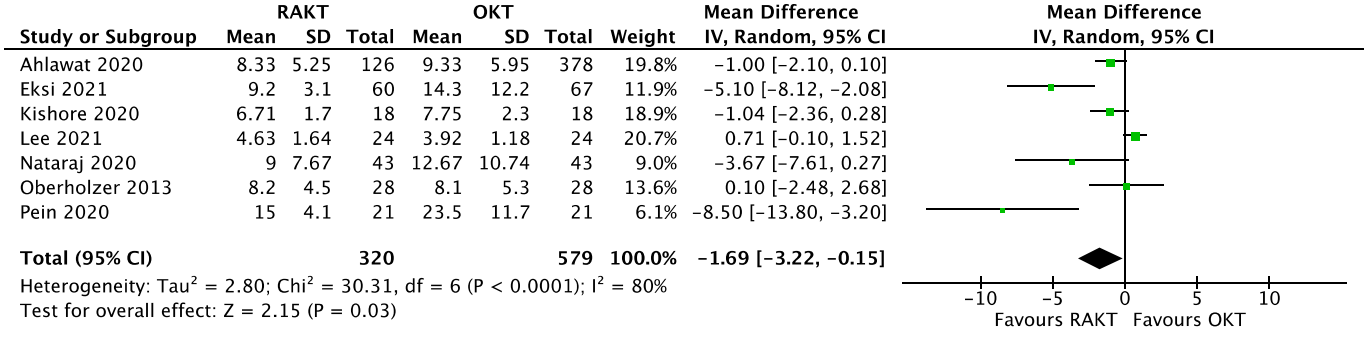


Fig. 1D. Hospital stay in days.

they reported beneficial effects of minimally invasive techniques for kidney transplantation. However, due to heterogeneity between the studies included in their systematic review, a meta-analysis was judged inappropriate, and consequently, recommendations on the preferred surgical technique could not be provided. A recently published meta-analysis compared RAKT and OKT [31]. It included a small number of studies, however, and fewer SSIs in the RAKT group was the only significant finding. In contrast, the higher number of studies included in our meta-analysis allowed to compare more outcomes parameters, especially those that are important for decision making. Therefore, this is the largest and most extensive systematic review and meta-analysis on RAKT so far.

RAKT is not without constraints. Firstly, robot-assisted surgery is more expensive compared to open surgical procedures. Not only is the acquisition of a robotic surgical system a major expense, the disposables needed for each surgery are costly too. Oberholzer et al. [7] reported significantly higher costs per surgery in the RAKT group compared with the OKT group. This could lead to a decreased access to RAKT in developing countries. On the other hand, a shorter hospital stay and decreased SSIs and symptomatic lymphoceles could lead to reduction in hospital costs per kidney transplantation. Moreover, total costs of a robotic surgical procedure do not have to be higher than open surgical procedures [32,33]. Additionally, new robotic surgical systems such as Senhance surgical systems and REVO-I have received regulatory approval in some countries [34] and others will enter the market shortly. Competition between manufactures will hopefully lead to a less expensive purchase of the robotic surgical system.

Another limitation of RAKT is its inability to perform anastomoses on arteries with severe atherosclerosis due to significantly less clamping force than Satinsky clamps [35]. As iliac artery disease is a common

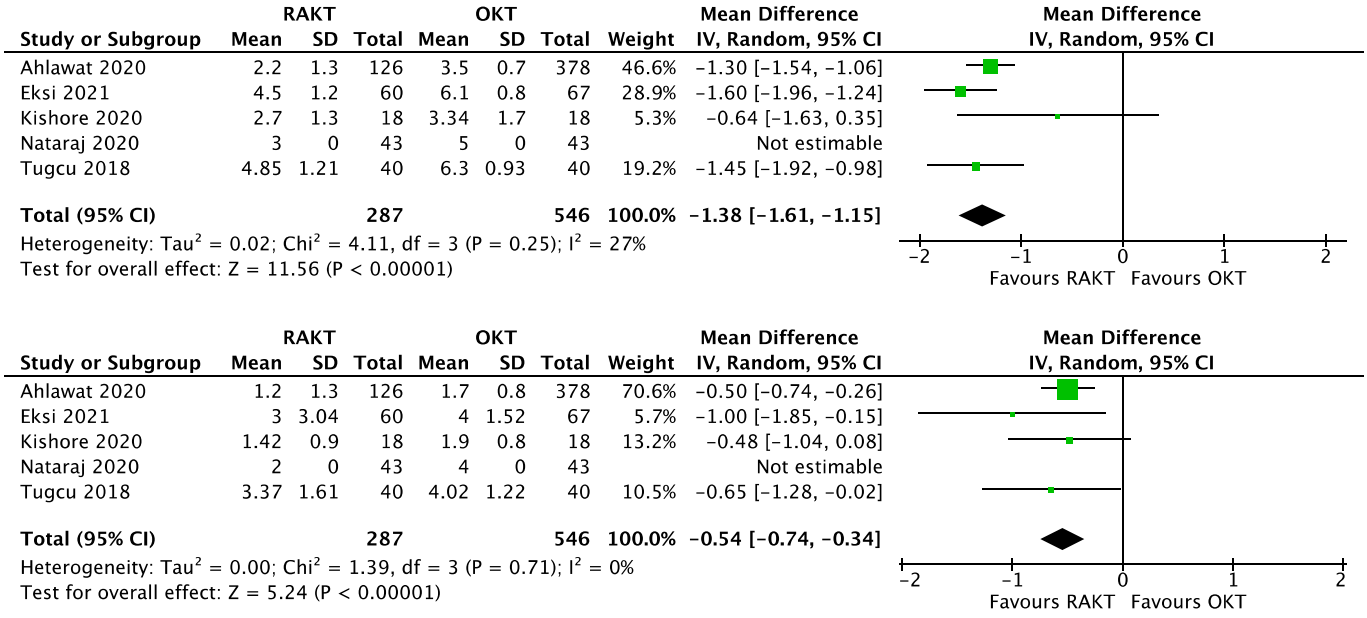


Fig. 2. Postoperative pain scores at 24 (a) and 48 (b) hours using the VAS-scale.

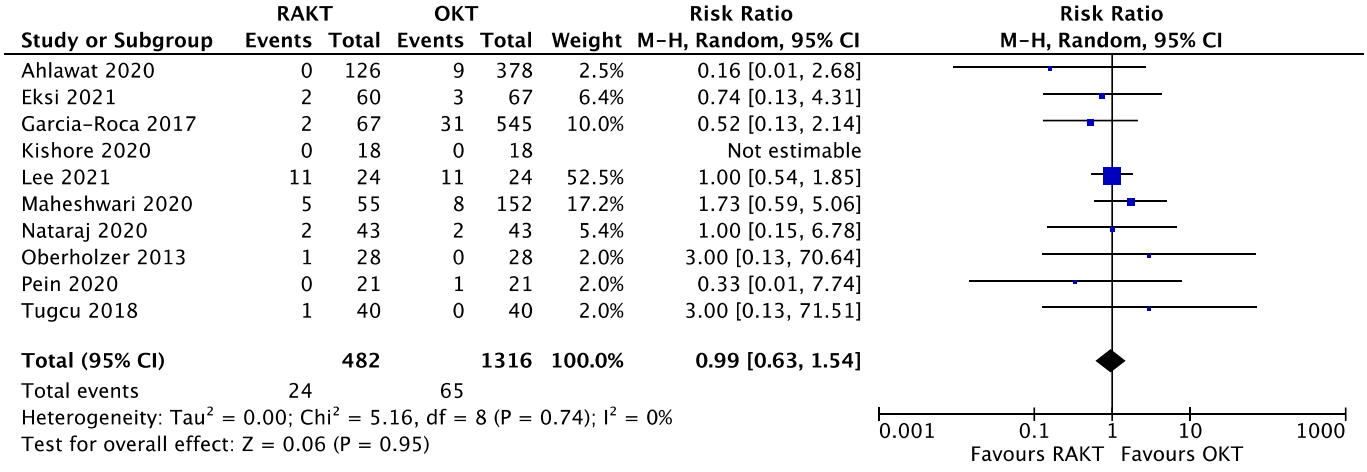


Fig. 3A. Delayed graft function (DGF).

problem in kidney transplant recipients [36], this is a serious drawback. A consequence of this limitation is that no kidney transplantation recipients with calcified iliac vessels were included in the studies included in this systematic review, and therefore our conclusions cannot be generalised to this population.

The majority of patients included in the reviewed studies received a living donor kidney. The study included by Lee et al. [28] showed the feasibility of RAKT performed in deceased donor kidney transplantation. Although no significant differences were found regarding CIT and post-operative renal function, available evidence is still very limited. As RAKT requires an expert surgical team, it is less feasible for deceased donor kidneys. Longer CIT waiting for the surgical team to become available will lead to a decrease in kidney quality and increase the risk of graft failure [37,38]. In addition, recipients of a deceased donor kidney are often waitlisted and on dialysis for a longer period of time compared to recipients of a living donor kidney [39]. The increase in dialysis duration could lead to more arteriosclerosis [40], which is a contraindication for RAKT. Therefore, RAKT is currently mostly feasible for living donor kidney transplantation.

OKT is a relatively easy technique to master with a short learning curve [41]. Ahlawat et al. [42] and Gallioli et al. [43]concluded that surgeons were able to perform RAKT independently within 21 and 35 cases respectively, without compromising renal function. However, the surgeons included in these studies already had experience in both robotic surgery and RAKT. Furthermore, Sood et al. [44] reported learning curves were significantly longer for surgeons inexperienced with robotic surgery for arterial, venous, ureterovesical anastomoses and ReWIT ($p < 0.05$) compared with surgeons with robotic experience. Therefore, the surgical learning curve should not be deemed as a disadvantage when implementing a new RAKT program. All studies included in this systematic review stated that RAKT was performed by an expert in both robotic surgery and OKT. Our results are therefore only applicable in cases where RAKT is performed by an experienced surgeon.

The majority of studies included in this systematic review reported longer ReWIT (Table 2). As longer ReWIT lowers renal function and both graft and patient survival [8–10], this unwanted hitch could be considered a major flaw. However, since the introduction of the regional hypothermic technique (covering the kidney in an ice-slush filled gauze

Table 4
Renal function after transplantation. NR = Not reported, OKT = Open kidney transplantation, RAKT = Robot assisted kidney transplantation, a = creatinine in mg/dL, b = eGFR in mL/min/1.73 m2.

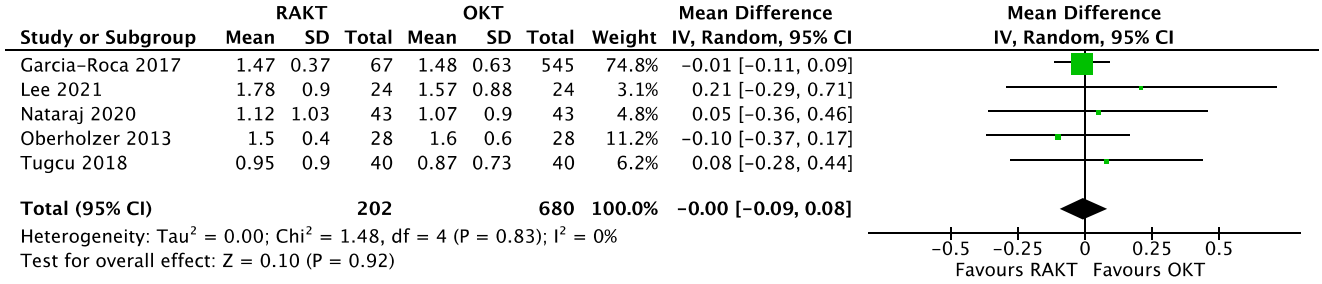
Study ID	Creatinine[a] 1 Month ±SD	eGFR 1 Month ±SD	Creatinine[a] 3 months	eGFR[b] 3 months	Creatinine[a] 6 months	eGFR[b] 6 months	Creatinine[a] 1 year	eGFR[b] 1 year	Creatinine[a] 3 years	eGFR[b] 3 years	Creatinine[a] 5 years	eGFR[b] 5 years
Oberholzer (2013)(7)	NR	NR	NR	NR	RAKT: 1.5 ± 0.4 OKT: 1.6 ± 0.6 *P = 0.47*	NR	NR	NR	NR	NR	NR	NR
Garcia-Roca (2017)(25)	NR	NR	NR	NR	RAKT: 1.47 ± 0.37 OKT: 1.48 ± 0.63 *P = 0.833*	RAKT: 55.27 ± 15.35 OKT: 54.44 ± 17.13 *P = 0.714*	RAKT: 1.42 ± 0.38 OKT: 1.5 ± 1.0 *P = 0.585*	RAKT: 58.47 ± 15.77 OKT: 55.37 ± 18.22 *P = 0.2221*	RAKT: 1.91 ± 1.68 OKT: 1.62 ± 0.95 *P = 0.171*	RAKT: 50.89 ± 21.55 OKT: 54.18 ± 21.82 *P = 0.462*	NR	NR
Spaggiari (2018)(20)	NR	NR	NR	NR	NR	NR	RAKT: 1.5 ± 0.5 OKT: 1.8 ± 1.3 *P = 0.56*	RAKT: 57 ± 20 OKT: 56 ± 25 *P = 0.94*	RAKT: 1.7 ± 1.3 OKT: 1.4 ± 0.8 *P = 0.30*	NR	RAKT: 2.4 ± 2.5 OKT: 1.4 ± 0.4 *P = 0.20*	RAKT: 44 ± 25 OKT: 57 ± 25 *P = 0.20*
Tugcu (2018)(18)	NR	NR	NR	NR	RAKT: 0.95 ± 0.90 OKT: 0.87 ± 0.73 *P = 0.638*	NR	NR	NR	NR	NR	NR	NR
Ahlawat (2020)(21)	NR	NR	NR	NR	NR	NR	RAKT: 1.2 (0.9–1.4) OKT: 1.2 (1–1.5) *P = 0.164*	NR	NR	NR	NR	NR
Kishore (2020)(26)	NR	RAKT = 55.5 OKT = 59	NR	NR	NR	RAKT: 63.3 ± 24 OKT: 66.5 ± 21 *P = 0.709*	NR	NR	NR	NR	NR	NR
Maheshwari (2020)(22)	RAKT: 1.41 ± 0.68 OKT: 1.19 ± 0.57 *< 0.001*	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Nataraj (2020)(23)	RAKT: 1.5 ± 1.4 OKT: 1.39 ± 1.3 *P = 0.5*	NR	RAKT: 1.25 ± 1.42 OKT: 1.14 ± 1.03 *P = 0.2*	NR	RAKT: 1.12 ± 1.03 OKT: 1.07 ± 0.9 *P = 0.4*	RAKT: 61.8 ± 16 OKT: 62.4 ± 24 *P = 0.9*	NR	NR	NR	NR	NR	NR
Pein (2020) (24)	RAKT: 1.65 ± 0.48 OKT: 2.07 ± 1.32	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Ekşi (2021) (27)	RAKT: 1.3 ± 0.4 OKT: 1.5 ± 1 *P = 0.108*	RAKT = 67.2 ± 23.2 OKT = 65.9 ± 25.1 *0.764*	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Lee (2021) (28)	RAKT: 1.83 ± 0.63	RAKT = 36.68 ± 15.34	RAKT: 1.58 ± 0.43	RAKT: 43.59 ± 15.51	RAKT: 1.78 ± 0.90	RAKT: 40.99 ± 19.17	RAKT: 1.66 ± 0.76	RAKT: 42.13 ± 22.79	NR	NR	NR	NR

(*continued on next page*)

Table 4 (*continued*)

Study ID	Creatinine[a] 1 Month ±SD	eGFR 1 Month ±SD	Creatinine[a] 3 months	eGFR[b] 3 months	Creatinine[a] 6 months	eGFR[b] 6 months	Creatinine[a] 1 year	eGFR[b] 1 year	Creatinine[a] 3 years	eGFR[b] 3 years	Creatinine[a] 5 years	eGFR[b] 5 years
	OKT: 1.85 ± 0.96	OKT = 41.85 ± 19.18	OKT: 1.53 ± 0.80	OKT: 47.10 ± 21.78	OKT: 1.57 ± 0.88	OKT: 43.84 ± 19.18	OKT: 1.55 ± 0.91	OKT: 50.28 ± 18.55				
	P = 0.96	*P = 0.32*	*0.78*	*P = 0.58*	*P = 0.51*	*P = 0.68*	*P = 0.77*	*P = 0.34*				

A



B

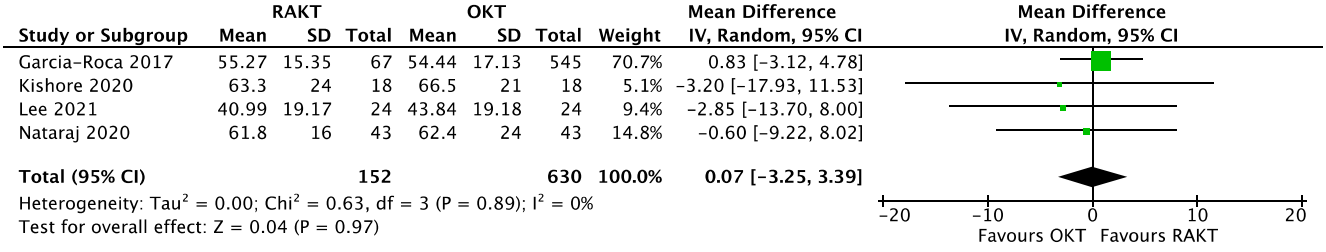


Fig. 3B. Serum creatinine (in mg/dL) (a) and eGFR (in mL/min/1.73 m^2) (b) at six-months post-transplantation.

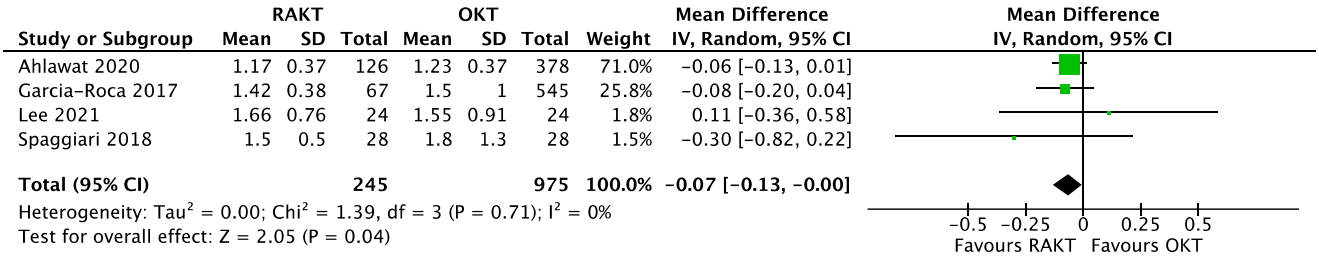
jacket) by Menon et al. [45] in 2014, this has become the standard technique in most RAKT centres. During rewarming the kidney is continuously cooled, thereby reducing anaerobic glycolysis. Because of the different circumstances of this warm ischemic period [46,47], we did not conduct a meta-analysis on this variable. The regional hypothermia could be the reason why no significant differences were found in both short- and long-term renal function. Nonetheless, only two studies reported long-term renal function and graft survival with a follow-up of more than three years, thus more extensive research is needed on long-term outcomes of RAKT.

4.1. Limitations

Several limitations of this study need to be addressed. Firstly, no RCT's on RAKT have been published yet. Therefore, the highest level of evidence could not be obtained. Secondly, only published articles are included and analysed, as conference abstracts were excluded. This might have led to publication bias. Nevertheless, our funnel plot analyses showed minimal evidence of publication bias for the most important outcomes. Thirdly, three [7,20,25,28,48]out of eleven studies focussed solely on obese recipients, therefore these outcomes cannot be generalised to the entire transplant population. These factors increase the potential of selection bias. Another point of critique is the various techniques used by the different centres to perform RAKT. Apart from the various type of incisions, the cooling method also differed among studies. To correct for heterogeneity as a consequence of these differences, we used a random effects model in the meta-analyses. Moreover, only three studies comparing 154 RAKT to 591 OKT recipients provided data for results at three-years post-operatively. Although these results are excellent, more research on long-term follow-up is needed to provide strong statements regarding renal function, graft and patient survival. In addition to this meta-analysis, a large case series by Tzvetanov et al. [48] of 239 obese RAKT recipients reported a 93% graft and 95% patient survival at three years, further demonstrates safety of the technique.

Finally, only 17 of 482 RAKT procedures (3.5%) of studies included in the meta-analysis were performed with a deceased donor kidney.

A



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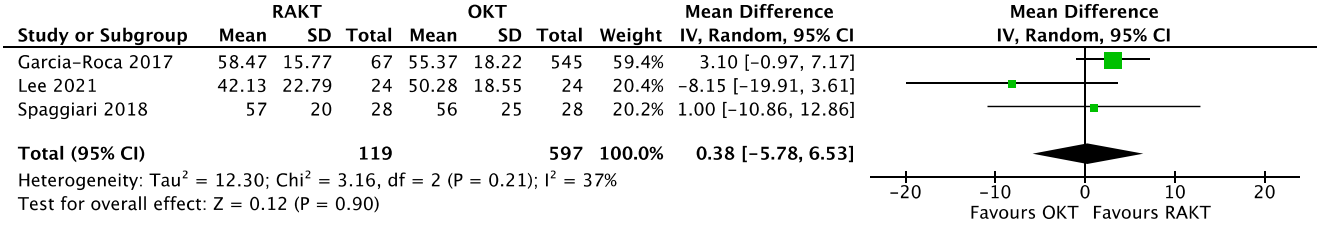

Fig. 3C. Serum creatinine (in mg/dL) (a) and eGFR (in mL/min/1.73 m^2) (b) at one-year post-transplantation.

Therefore, our results cannot directly be translated to recipients of deceased donor kidneys. Although it is likely that surgical outcomes such as SSI and post-operative pain are comparable between living and deceased donor kidney recipients [3], outcomes on renal function, graft and patient-survival cannot be equalized, especially since longer ReWIT in RAKT could be more hazardous to the fragile deceased donor kidney graft. Further research on RAKT compared to OKT is needed to investigate if similar results can be achieved for deceased donor kidney recipients. RCT's on both living and deceased donor kidney transplantation are desired to truly establish the additional value of RAKT compared to OKT.

5. Conclusions

RAKT from (living) donor kidneys is a safe and feasible technique, associated with a decreased risk of surgical complications in selected patients when performed by an experienced surgeon, without compromising (long-term) renal function as well as graft and patient survival. RAKT offers an excellent alternative to OKT, by adding the benefits of minimally invasive surgery.

Ethical approval

Not applicable.

Funding

This research did not receive any form of funding.

Author contribution

J.S. Slagter; study design, data collection, data anlysis, writing. L. Outmani; data collection, careful review of the manuscript. T.C.K. Tran: careful review of the manuscript. J.N.M. IJzermans: careful review of the manuscript. R.C. Minnee: study design, careful review of the manuscript, principal investigator.

Registration

This review was registered in Research Registry.
Number: reviewregistery1206.
Register Your Systematic Review- Research Registry.

Guarantor

R.C. Minnee.
J.S. Slagter.

Data statement

As this is a systematic review, the data is public via databases to everyone. However, data is available from the corresponding author upon request.

Declaration of competing interest

None.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Declaration of competing interest

None.

Acknowledgements

We would like to acknowledge Wichor Bramer and Sabrina Meertens-Gunput, medical librarians of the Medical Library of the Erasmus MC University Medical Center Rotterdam, for their help in compiling the search strategy and in the search process.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijsu.2022.106264.

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