Review Article

Comparison of outcomes after open versus robotic kidney transplantation: A systematic review and meta-analysis

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ABSTRACT

Introduction: This meta-analysis compares the clinical outcomes of robot-assisted kidney transplant (RAKT) to open kidney transplant (OKT).

Methods: A systematic search of Scopus and MEDLINE databases was carried out using a combination of keywords to identify studies comparing RAKT to OKT. Baseline characteristics and preoperative and postoperative data were collected along with data on the short- and long-term outcomes. The study was registered in PROSPERO and Assessing the Methodological Quality of Systematic Reviews and Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines were followed.

Results: A total of 16 studies were included with a total of 2555 patients, of which 677 underwent RAKT and 1878 underwent OKT. This meta-analysis shows a significant benefit of RAKT over OKT in terms of less intra-operative blood loss, smaller incision length, less postoperative pain scores at 24 and 48 hours, and a lower incidence of surgical site infections (SSIs), especially in obese patients. In addition, the incidence of postoperative lymphoceles was lower in the RAKT group compared to the OKT group, although not statistically significant. There was no difference between the two groups in terms of short-term graft functional outcomes and overall survival. The number of deceased donor recipients undergoing RAKT was very small. At the time of reporting this meta-analysis, no randomized controlled trials (RCTs) had been published.

Conclusion: This meta-analysis showed that RAKT is a safe and feasible alternative to OKT, especially in obese individuals. Further trials are needed to confirm the safety, efficacy, and cost-effectiveness of RAKT.

INTRODUCTION

The minimally invasive approach to kidney transplantation in the recipient using robotic surgical platforms has gained popularity in recent times.[1] Initially developed to minimize the complications and morbidity of open surgeries, especially in obese patients, robot-assisted kidney transplant (RAKT) has proven to be as good as open method in terms of functional and graft outcomes, even in patients of pediatric age group.[2,3] Studies on RAKT have shown decreased postoperative analgesic requirements, lower incidence of surgical site infection (SSI), and other local wound complications and better convalescence as compared to open kidney transplantation (OKT).[2] However, concerns continue to exist regarding higher warm ischemia times (WITs) in

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the robotic approach which may translate into inferior graft outcomes. As robotic surgical platforms become more widely available and a greater number of surgeons are getting trained in robotic surgeries every year, it becomes pertinent to examine whether RAKT has the potential to replace OKT as the gold standard the same way laparoscopic donor nephrectomy has replaced open donor nephrectomy. This systematic review and meta-analysis compares the surgical outcomes of RAKT versus OKT along with the graft function and graft and patient survival between these two.

MATERIALS AND METHODS

Search strategy

We searched the online databases of Medline and Scopus using keywords "kidney", "transplantation" and "robotic". We used the Boolean operators ("Kidney OR renal OR organ" AND "Transplantation OR transplant OR graft" AND "robotic OR robot OR da Vinci" AND "open"). We also searched the references of any earlier systematic reviews and meta-analysis. The date range was from January 2002 (first robotic transplant in the world) to July 31, 2022. The studies were exported to a citation manager and references were reviewed to assess whether any relevant studies have been left out.

Study selection

We used the PICOS format for study eligibility assessment (population, intervention, compare, outcome, and study design) and specified the individual elements as: P: kidney transplant recipients; I: RAKT, renal transplantation via minimally invasive technique using a surgical robot; C: OKT; O: surgical outcomes, (long-term) renal function, patient and graft survival; S: randomized and nonrandomized studies. This meta-analysis was registered in PROSPERO (Reg. No. CRD-42022350690). We included studies that compared operative and functional outcomes of robotic and open renal transplantation. We included prospective and retrospective cohort studies and randomized controlled trials (RCTs). We excluded case reports, animal studies, case series, reviews, commentaries, conference meetings/abstracts, and studies on other modalities apart from robotic and open renal transplantation. The titles and abstracts were used to select studies, whose full texts were reviewed. Finally, studies which fulfilled our inclusion criteria were selected for the meta-analysis. This process was done by two authors (K. M. and R. J.) and any disagreements were settled after consultation with the senior authors (M. B. and A. P.). Assessing the Methodological Quality of Systematic Reviews and Preferred Reporting Items for Systematic Review and Meta-Analysis guidelines were followed [Supplemental Figure S1].[4,5]

Outcomes

Data extraction was done by two authors independently (K. M. and R. J.). Data on number of patients, operating time, anastomosis times (arterial, venous, and uretero-vesical), ischemia times (warm, cold, and re-warming ischemia times), incision length, blood loss, conversion rates (to open), pain scores, analgesic requirements, wound infections, lymphocele, graft thrombosis and stenosis, ureteral complications, re-exploration, delayed graft function (DGF), deep-vein thrombosis (DVT), urinary tract infections (UTIs), hospital stay, serum creatinine levels, and estimated glomerular filtration rates at 1 week, 1 month, 6 months and 1 year, rejection, graft and overall survival from 1 to 5 years was retrieved. DGF was defined as requirement of dialysis in the first week after transplantation. Rewarming time in RAKT was defined as the time between placing the kidney graft into the peritoneal cavity and reperfusion of the kidney after vascular anastomoses.

Quality assessment

The quality of included studies was assessed using the Newcastle Ottawa Scale (NOS)[6] by two independent authors (K. M. and R. J.) [Supplemental Table 1]. Publication bias was assessed using Egger's test and Funnel plot. In case, the results were significant, failsafe N was used to assess publication bias and find the number of studies needed to render the results insignificant. Rosenthal's formula (5k + 10) was used as the threshold for failsafe N, where k is the number of studies included.

Statistical analysis

Data were extracted from all included studies into standardized forms and then into Microsoft Excel 2007 for Windows (Microsoft Corporation, Redmond, Washington, USA) and Comprehensive Meta-Analysis version 3 (Biostat Inc., Englewood, New Jersey, USA). We used the random effects model to synthesize results. For continuous variables, Hedge's g was calculated along with a 95% confidence interval (95% CI) and *P* value. Standardized difference in means was used when units of the variable were different among the studies. Pooled risk-ratios were used for dichotomous variables. $P < 0.05$ was considered significant. Heterogeneity was assessed using Tau-squared and I-squared statistic and prediction interval.

RESULTS

Included studies and study characteristics

Our search yielded 1681 citations and 16 studies were selected for inclusion in our meta-analysis as shown in Supplemental Figure S1.[1,3,7-20] All studies were of good quality as per the NOS [Supplemental Table 1]. The baseline characteristics of the studies included are shown in Supplemental Table 2. These studies included a total of 2555 patients, of which 677 underwent RAKT and 1878 underwent OKT. Two of the studies, Oberholzer *et al*. and Spaggiari *et al*. reported on the same patients and hence were included together for quantitative analysis.[19,20] Further, Garcia-Roca *et al*. reported separately on some

parameters for patients depending on their Body Mass Index (BMI less than and more than 45 kg/m^2) and these two sub-groups were included separately for quantitative analysis.[9] No RCTs were published at the time of screening.

Perioperative outcomes

Operative time

Total operative time was reported by 11 studies (RAKT-523, OKT-1132) and was not significantly higher in either group (Hedge's g 0.127, 95% CI-0.036–0.290 $P = 0.128$) [Figure 1].[1,7,8,10-12,14-18] Publication bias is depicted in Supplemental Figure S2a, and the funnel plot was symmetrical. Heterogeneity was moderate as suggested by an I^2 statistic of 47.711% and Tau-squared of 0.033. Further, the prediction interval of effect size varied from –0.32 to 0.58.

Arterial anastomoses time

Arterial anastomoses time was reported by four studies (RAKT-202, OKT-358) and was not significantly different among the two groups (Hedge's g 0.167 95% CI-0.395–0.728 $P = 0.561$) [Figure 1].[7,10,14,18] Publications bias is depicted in Supplemental Figure S2b. There was significant heterogeneity with I2 statistic of 88.827% and Tau-squared of 0.289. The prediction interval of effect size varied from –2.45 to 2.79.

Venous anastomoses time

Venous anastomoses time was reported by four studies (RAKT-202, OKT-358) and was not significantly different among the two groups (Hedge's g 0.207 95% CI-0.334–0.748 $P = 0.454$) [Figure 1].[7,10,14,18] Publication bias is shown in Supplemental Figure S2c. There was significant heterogeneity with I2 statistic of 88% and Tau-squared of 0.265. The prediction interval of effect size varied from –2.31–2.72.

Uretero-vesical anastomoses time

Uretero-vesical anastomoses time was reported by four studies (RAKT-202, OKT-358) and was not significantly different among the two groups (Hedge's g 0.247 95% CI-0.219–0.713 P value 0.3) [Figure 1].[7,10,14,18] Publication bias is shown in Supplemental Figure S2d. There was significant heterogeneity with I2 statistic of 83.917% and Tau-squared of 0.187. The prediction interval of effect size varied from –1.88 to 2.37.

Warm ischemia time

WIT was reported by eight studies (RAKT-412, OKT-987) and was not significantly different among the two groups (Hedge's g 0.077 95% CI-0.125–0.278 $P = 0.454$) [Figure 1].[1,3,10,13-16,18] Publication bias is shown in Supplemental Figure S2e. There was moderate heterogeneity with I2 statistic of 55.26% and Tau-squared of 0.041. The prediction interval of effect size varied from –0.48 to 0.63.

Cold ischemia time

Cold ischemia time (CIT) was reported by nine studies (RAKT-436, OKT-1011) and was higher in the RAKT group (Hedge's g-0.353 95% CI 0.15–0.555 P value < 0.001) [Figure 1].[1,3,10,12-16,18] Publication bias is shown in Supplemental Figure S2f. Egger's test was nonsignificant with a $P = 0.692$. There was mild heterogeneity with I2 statistic of 35.663% and Tau-squared of 0.02. The prediction interval of effect size varied from –0.06 to 0.71.

Re-warm ischemia time

Re-WIT was reported by 14 studies (RAKT-436, OKT-1011) and was higher in the RAKT group (Hedge's g 0.410, 95% CI 0.237–0.583 $P < 0.001$) [Figure 1].[1,3,7,8,10-20] Publication bias is shown in Supplemental Figure S2g with nonsignificant Egger's test showing P value of 0.73861. There was moderate heterogeneity with I2 statistic of 59.482% and Tau-squared of 0.058. The prediction interval of effect size varied from – 0.15 to 0.97.

Intra-operative blood loss

Intra-operative blood loss was reported by 12 studies (RAKT-564 OKT-1288) and this was significantly less in the RAKT group (Hedge's g-0.398 95%–0.537–-0.259 $P < 0.001$) [Figure 1].[1,3,7,8,10-14,17-20] Orwin's failsafe N was 34. Publication bias is shown in Supplemental Figure S2h with nonsignificant Egger's test showing $P = 0.35331$. There was mild heterogeneity with I2 statistic of 19.954% and Tau-squared of 0.019. The prediction interval of effect size varied from –0.74 to –0.05.

Incision length

Incision length was reported by 6 studies (RAKT-385 OKT-854) and the incision was significantly smaller in the RAKT group (Hedge's g –0.567 95%–0.788–-0.347 $P < 0.001$) [Figure 1].[1,8,10,11,14,18] Orwin's failsafe N was 285. Publication bias is shown in Supplemental Figure S2i with significant Egger's test showing $P = 0.01329$. There was moderate heterogeneity with I2 statistic of 58.826% and Tau-squared of 0.041. The prediction interval of effect size varied from –1.21 to 0.08.

Pain scores

Studies reported on pain scores at 12, 24, 36, 48, and 96 h. We included 6 studies that reported on pain scores at 24 and 48 h (RAKT-385 OKT-854).[1,8,10,11,14,18] Pain score at 24 h was lower in the RAKT group (Hedge's g – 0.45 95%CI – 0.578– –0.322 $P < 0.0001$) [Figure 1]. Orwin's failsafe N was 21. Publication bias is shown in Supplemental Figure S2j with a nonsignificant Egger's test showing P value of 0.28337. There was no heterogeneity with I2 statistic of 1.177% and Tau-squared of 0. There was no dispersion. Similarly, pain score at 48 h was significantly lower in the RAKT group (Hedge's g – 0.315 95%CI –0.613–-0.017 $P < 0.038$) [Figure 1]. Orwin's failsafe N was 12. Publication bias is shown in Supplemental Figure S2k with a

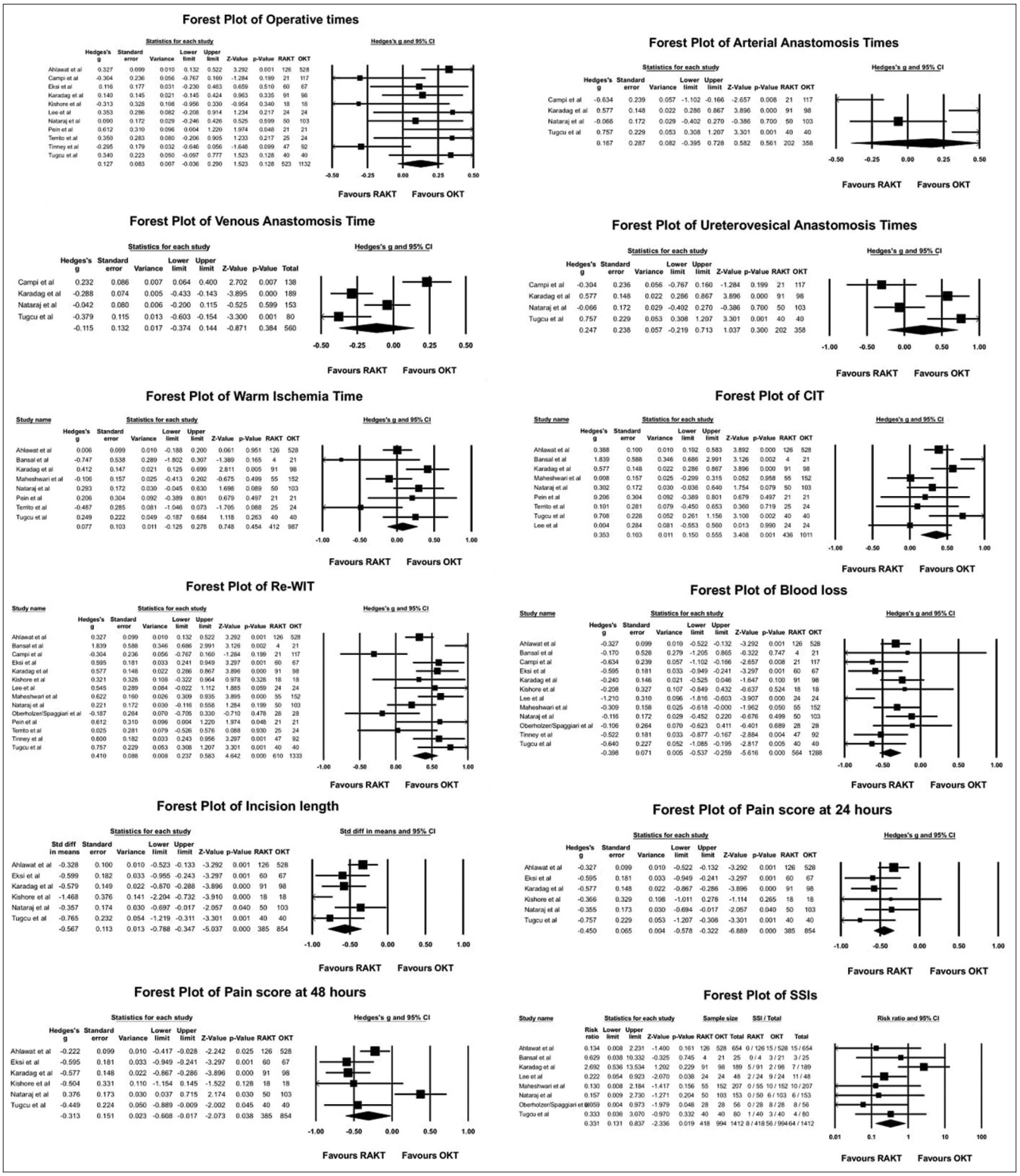

Figure 1: Forest plots of operative time, arterial anastomosis time, venous anastomosis time, ureterovesical anastomosis time, WIT, CIT, Re-WIT, blood loss, incision length, pain scores at 24-and 48-h and SSIs. WIT: Warm ischemia times, CIT: Cold ischemia time

nonsignificant Egger's test showing *P* value of 0.74174. There was significant heterogeneity with I2 statistic of 78.126% and Tau-squared of 0.101. The prediction interval of effect size varied from –1.29–0.66.

Surgical site infections

SSIs were reported by 8 studies (RAKT-418 OKT-994) and were significantly less in the RAKT group (RR-0.331 95% CI 0.131–0.837 *P* value-0.019) [Figure 1].[1,3,10,12-14,18-20]

There was mild heterogeneity with I2 statistic of 26.015% and Tau-squared of 0.454. Orwin's failsafe N was 70. Publication bias is shown in Supplemental Figure S3a with a nonsignificant Egger's test showing *P* value of 0.24498. The prediction interval of effect size varied from 0.04–2.48.

Incisional hernia

Incisional hernias were reported by Maheshwari *et al*. and Tinney *et al*. Maheshwari *et al*. reported 2 hernias (3.6%) in the RAKT and none in the OKT group.[13] Tinney *et al*. reported 1 case of incisional hernia in both RAKT (2.2%) and OKT (1.1%) groups.[17]

Lymphocele

Lymphocele was reported by 8 studies (RAKT-299 OKT-544) and it was lower in the RAKT group, but did not reach statistical significance (RR-0.468 95% CI –0.152–1.44 *P* = –0.185) [Figure 2].[7,10,12,13,15,17,18] There was no heterogeneity with I2 statistic of 0 and Tau-squared of 0. Publication bias is shown in Supplemental Figure S3b with a nonsignificant Egger's test showing *P* value of 0.98406. There was no dispersion of effect sizes.

Graft thrombosis and stenosis and ureter-related complications

Graft thrombosis and stenosis were reported by 8 studies (RAKT-421 and OKT-1501) and there was no statistically significant difference among the two groups (RR-0.588, 95% CI –0.212–1.628, *P* value-0.307) [Figure 2].[1,7,9,10,13,15,18] There was no heterogeneity with I2 statistic of 0 and Tau-squared of 0. Publication bias is shown in Supplemental Figure S3c with a significant Egger's test showing *P* value of 0.01385. There was no dispersion of effect sizes. Ureter-related complications were reported by three studies, which reported 1 and 4 incidences in the RAKT and OKT groups, respectively.

Delayed graft function

DGF was reported by 10 studies (RAKT-540, OKT-1672) and there was no statistically significant difference between the two groups (RR-0.927, 95% CI – 0.614–1.401 *P* = –0.72) [Figure 2].[1,7-10,12,13,15,17,19,20] The RAKT group reported 29 (5.37%) incidents of DGF and the OKT group reported 99 incidents (5.92%). There was no heterogeneity with I2 statistic and Tau-squared of 0. There was no dispersion of effect sizes. The publication bias is shown in Supplemental Figure S3d with a nonsignificant Egger's test of 0.75579.

Urinary tract infections

UTIs were reported by 5 studies (RAKT-285, OKT-28) and there was no significant difference between the two groups (RR-1.164, 95%CI –0.597–2.267 *P* = –0.656) [Figure 2].[1,9,11,12,14] The RAKT group reported 12 (4.21%) incidents of UTI and the OKT group reported 28 incidents (2.3%). There was no heterogeneity with I2 statistic and Tau-squared of 0. There was no dispersion of effect sizes. The publication bias is shown in Supplemental Figure S3e with a nonsignificant Egger's test of 0.44374.

Length of hospital stay

Length of hospital stay was reported by 12 studies (RAKT-557, OKT-1662) and it did not differ significantly between the two groups (Hedge's g-0.088, 95% CI –0.278–0.102, *P* = –0.365) [Figure 2].[1,3,7-11,14,15,17,19,20] There was significant heterogeneity with I2 statistic of 65.083% and Tau-squared of 0.254. The prediction interval of effect sizes was –1.23–1.06. There was no publication bias as shown in Supplemental Figure S3f with a nonsignificant Egger's test of 0.7648.

Acute rejection

Events of acute rejection were reported by six studies (RAKT-196, OKT-788) and there was no significant difference between the two groups (RR-1.215, 95% CI – 0.718–2.057 *P* = 0.467) [Figure 2].[3,9,11-13,19,20] The RAKT group reported 20 (10.2%) incidents of acute rejection and the OKT group reported 37 incidents (4.7%). There was no heterogeneity with I2 statistic and Tau-squared of 0. There was no dispersion of effect sizes. The publication bias is shown in Supplemental Figure S3g with a nonsignificant Egger's test of 0.88554.

Serum creatinine at 1 month

Serum creatinine at 1 months was reported by five studies (RAKT-139, OKT-209) and there was no significant difference between the two groups (Hedge's g-0.036, 95% CI –0.267–0.194, *P* = 0.757) [Figure 2].[3,12,14,15,18] There was mild heterogeneity with I2 statistic of 6.836% and Tau-squared of 0.071. The prediction interval of effect sizes was –0.96–0.89. There was no publication bias as shown in Supplemental Figure S3h with a nonsignificant Egger's test of 0.38385.

Serum creatinine at 6 months

Serum creatinine at 6 months was reported by 5 studies (RAKT-209, OKT-740) and there was no significant difference between the two groups (Hedge's g 0.035, 95% CI – 0.130–0.201, *P* = 0.674) [Figure 2].[9,12,14,18-20] There was no heterogeneity with I2 statistic of 0 and Tau-squared of 0. There was no dispersion of effect sizes. There was no publication bias as shown in Supplemental Figure S3i with a nonsignificant Egger's test of 0.79341.

Serum creatinine at 1 year

Serum creatinine at 6 months was reported by 4 studies (RAKT-166, OKT-689) and there was no significant difference between the two groups (Hedge's g-0.022, 95% CI-0.203–0.158, *P* = 0.809) [Figure 2].[9,12,17,19,20] There was no heterogeneity with I2 statistic of 0 and Tau-squared of 0. There was no dispersion of effect sizes. There was no publication bias as shown in Supplemental Figure S3j with a nonsignificant Egger's test of 0.8.

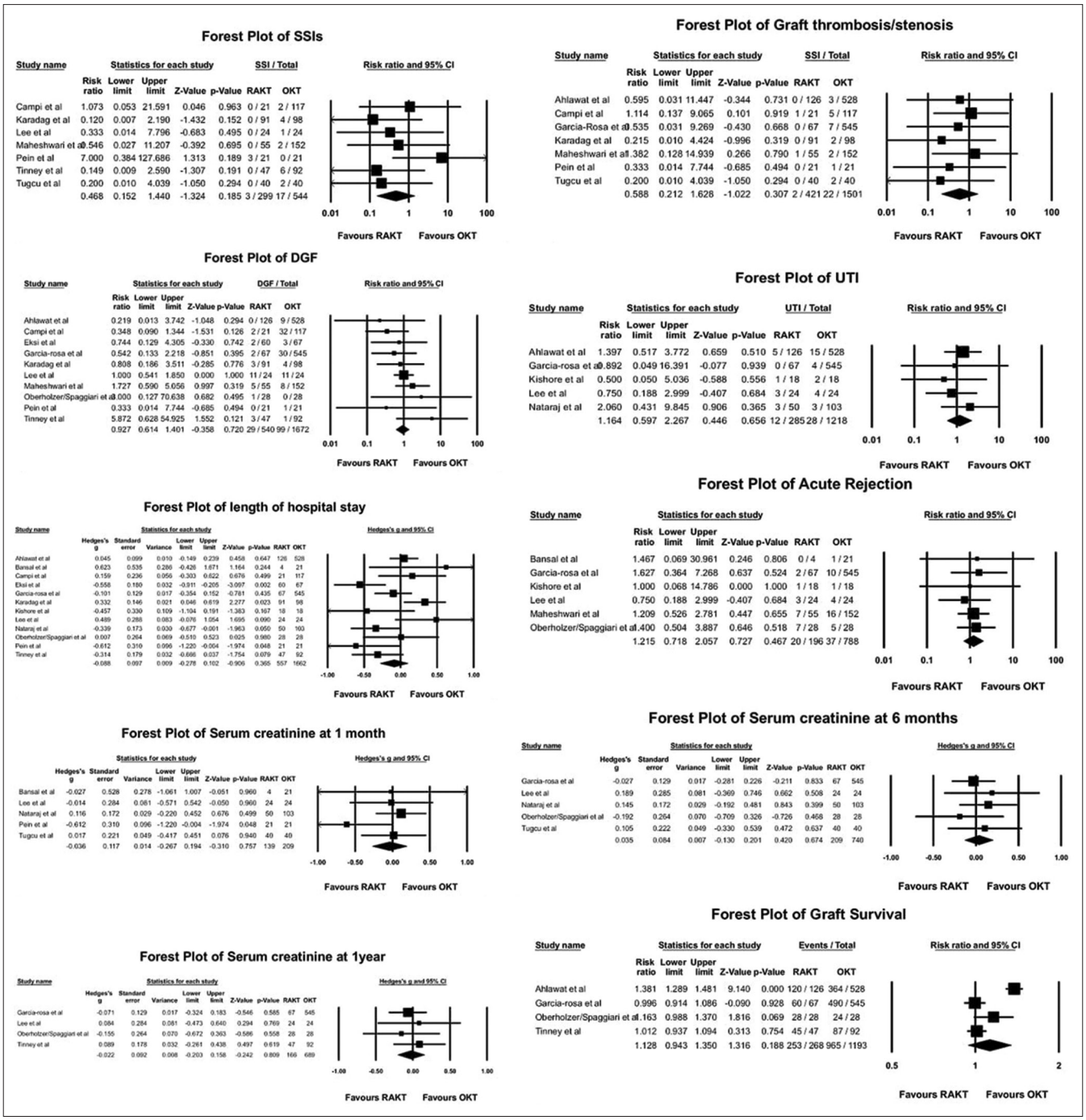

Figure 2: Forest plots of lymphoceles, graft complications, delayed graft function, urinary tract infections, length of hospital stay, acute rejection, serum creatinine at 1 month, 6 months, and 1 year and graft survival

Graft survival

Graft survival at 3 years was reported by 4 studies (RAKT-268, OKT-1193) and there was no significant difference between the two groups (RR-1.128, 95% CI 0.943–1.35, *P* value-0. yt) [Figure 2].[1,9,17,19,20] There was no heterogeneity with I2 statistic of 0 and Tau-squared of 0. There was no dispersion of effect sizes. The dispersion of effect size ranged from 0.48 to 2.65. There was no publication bias as shown in Supplemental Figure S3k with a nonsignificant Egger's test of 0.8.

Overall survival

Overall survival at 3 years was reported by 3 studies (RAKT-201, OKT-648) and there was no significant difference between the two groups (RR-0.978, 95% CI 0.943–1.013, *P* value-0.217).[1,17,19,20] There was no heterogeneity with I2 statistic of 0 and Tau-squared of 0. There was no dispersion of effect sizes. There was no publication bias as shown in Supplemental Figure S3l with a nonsignificant Egger's test of 0.3.

DISCUSSION

This meta-analysis shows a significant benefit of RAKT over OKT in terms of intra-operative blood loss, incision length, postoperative pain scores at 24 and 48 h, and incidence of SSIs. In addition, the incidence of postoperative lymphoceles was also lower in the RAKT group compared to the OKT group, albeit not statistically significant. There was no difference between the two groups in terms of short-term graft functional outcomes and overall survival. There are a few published systematic reviews and meta-analyses on RAKT versus OKT.[2,21,22] The studies included in the earlier ones were either too heterogeneous in nature or too few in number to formulate definitive recommendations on the use of RAKT over OKT. The largest meta-analysis published included 11 studies and compared 482 RAKT procedures with 1316 OKT procedures.[2] This meta-analysis includes 16 studies in total and compares 677 RAKT with 1878 OKT procedures, thus providing more comprehensive and robust data on this topic.

Obese patients have a higher incidence of SSIs and in the past, transplant registries often allotted longer waiting times to such patients.[23,24] The incidence of SSIs in such patients is directly related to decreased graft survival rates.[23] RAKT has a lower incidence of SSIs compared to OKT. The vascular and ureteral anastomoses times and the graft outcome are comparable with those reported for OKT. While there is no randomized control trial comparing these two modalities, there is convincing evidence to recommend RAKT as the preferred method of renal transplant in obese end stage renal disease patients. However, patients with obesity form only a subset of patients undergoing kidney transplant. In the absence of well powered RCTs comparing RAKT with OKT, it may be too premature to extrapolate these findings to the general population. Among patients with obesity, Garcia-Roca *et al*. showed that there was no correlation between BMI and long-term renal function, graft survival, and overall survival.[9]

There are concerns regarding the use of RAKT in deceased donors. Lee *et al*. had reported on the comparison of RAKT with OKT in patients with deceased donors amongst their study population and did not find any difference between CITs and postoperative graft function.[12] However, grafts from deceased donors traditionally have longer CITs compared to grafts from living donors. That combined with longer waiting periods on dialysis for recipients of deceased donor kidneys and an extended CIT, to assemble a robotic transplant surgery team to perform the transplant may translate into worse outcomes. Campi *et al*. have reported on 138 patients of deceased donor renal transplant of which 21 patients underwent RAKT.[7] In their study, there was no difference between the ReWIT and graft outcomes between RAKT and OKT. While a comprehensive decision-making process can ensure good outcomes of RAKT even in patients with deceased donors, it is important to understand that the results of this study may not translate into clinical practice. Deceased donor kidney transplants are often semi-emergency surgeries and unless a center has a dedicated robotic suite and team always ready for a RAKT, logistic issues in arranging a RAKT procedure may result in worse graft outcomes.

Most studies included in our meta-analyses report longer ReWIT for RAKT. However, the use of hypothermic cooling method described by Menon *et al*. using an ice slush filled gauze jacket to cover the kidney has become standard practice in almost all centers doing RAKT and helps to reduce anaerobic glycolysis during the rewarming period.[25] This may explain the higher rates of acute rejection in the RAKT group, but this was not statistically significant. The higher rate of rejection in the RAKT group can also be explained by the fact that one of the studies had a higher proportion of immunologically high-risk patients in this group including patients with panel-reactive antibodies and B-cell positive crossmatch.[9]

Among patients that require a biopsy following RAKT, this may have to be done laparoscopically. Ahlawat *et al*. demonstrated that routine extraperitonealization avoided this and also prevented graft torsion and other complications associated with intra-peritoneal placement of graft.[1,20]

Only a few of the included studies have included long-term renal function and graft survival. Hence, it is difficult to make an accurate observation on the effect of RAKT on long-term graft function. The studies that do report on this parameter mention no difference in outcomes between RAKT and OKT.

RAKT is not without its shortcomings. The initial cost of setting up a robotic surgical system combined with disposables used in surgery makes robotic surgery costly. Availability, especially in developing countries, along with the cost, makes RAKT inaccessible in many centers. Shorter hospital stays and lower incidence of SSIs and less pain may translate into cost benefits. However, these need to be proven in large scale studies specifically investigating such an outcome.

RAKT has a learning curve of around 25 cases and requires coordination between the surgeon and the assistant to reduce ischemia time.[26-28] Those with relative inexperience in robotic surgery have longer learning curves.[29] RAKT can be challenging in patients with significant atherosclerosis. The standard imaging done for any potential kidney recipient is usually a color Doppler of the iliac vessels. If there is evidence of atheromatous plaques on the Doppler, a contrast angiogram and application of AI powered methods may help in making RAKT feasible in such patients.[30]

Limitations

This meta-analysis has limitations. Due to absence of RCTs in this field, the evidence provided is not of the highest quality. Of the 16 studies, 6 were retrospective cohorts and 10 were prospective. Random effects model was used, but there is some heterogeneity in the meta-analysis arising from variations in multiple parameters including age, BMI, time on dialysis, technique of anastomosis, cooling method, time on dialysis, and immunosuppression regime. Only one of the studies investigated paediatric population and the results of this meta-analysis cannot be extrapolated to this age group. Similarly, only 3 studies included deceased donors and 3 included obese patients and extrapolation of these results to these groups may not be feasible. There was some heterogeneity in the units used by different studies for analgesic requirement and evaluation of renal function. There was lack of availability of studies on long-term functional outcomes and survival of both modalities of renal transplant.

CONCLUSION

RAKT is a safe and feasible technique and can be offered as an alternative to OKT in experienced hands. It offers the advantages of minimally invasive surgery such as decreased blood loss, pain scores, incision length, and SSIs. It is associated with comparable operative and anastomotic times and long-term outcomes. There is a need for RCTs on larger populations, including obese patients, pediatric age group, and deceased donors.

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Supplemental Table 1: Assessment of included studies via Newcastle Ottawa Scale (NOS)

Study	Selection				Comparability	Outcome			AHRQ standards
	Representativeness of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis controlled for confounders	Assessment of outcome	Was follow-up long enough for outcomes to occur	Adequacy of follow-up of cohorts	
Ahlawat *et al.*	1	1	1	1	2	1	1	1	Good
Bansal *et al.*	1	1	1	1	2	1	1	1	Good
Campi *et al.*	1	1	1	1	1	1	1	1	Good
Eksi *et al.*	1	1	1	1	2	1	1	1	Good
Garcia-Roca *et al.*	1	1	1	1	1	1	1	1	Good
Karadag *et al.*	1	1	1	1	1	1	1	1	Good
Kishore *et al.*	1	1	1	1	1	1	1	1	Good
Lee *et al.*	1	1	1	1	2	1	1	1	Good
Maheshwari *et al.*	1	1	1	1	2	1	1	1	Good
Nataraj *et al.*	1	1	1	1	2	1	1	1	Good
Pein *et al.*	1	1	1	1	1	1	1	1	Good
Territo *et al.*	1	1	1	1	2	1	1	1	Good
Tinney *et al.*	1	1	1	1	1	1	1	1	Good
Tugcu *et al.*	1	1	1	1	1	1	1	1	Good
Spaggiari *et al.*	1	1	1	1	2	1	1	1	Good
Oberholzer *et al.*	1	1	1	1	2	1	1	1	Good

AHRQ=Agency for Healthcare Research and Quality

Supplemental Table 2: Baseline characteristics of the studies included

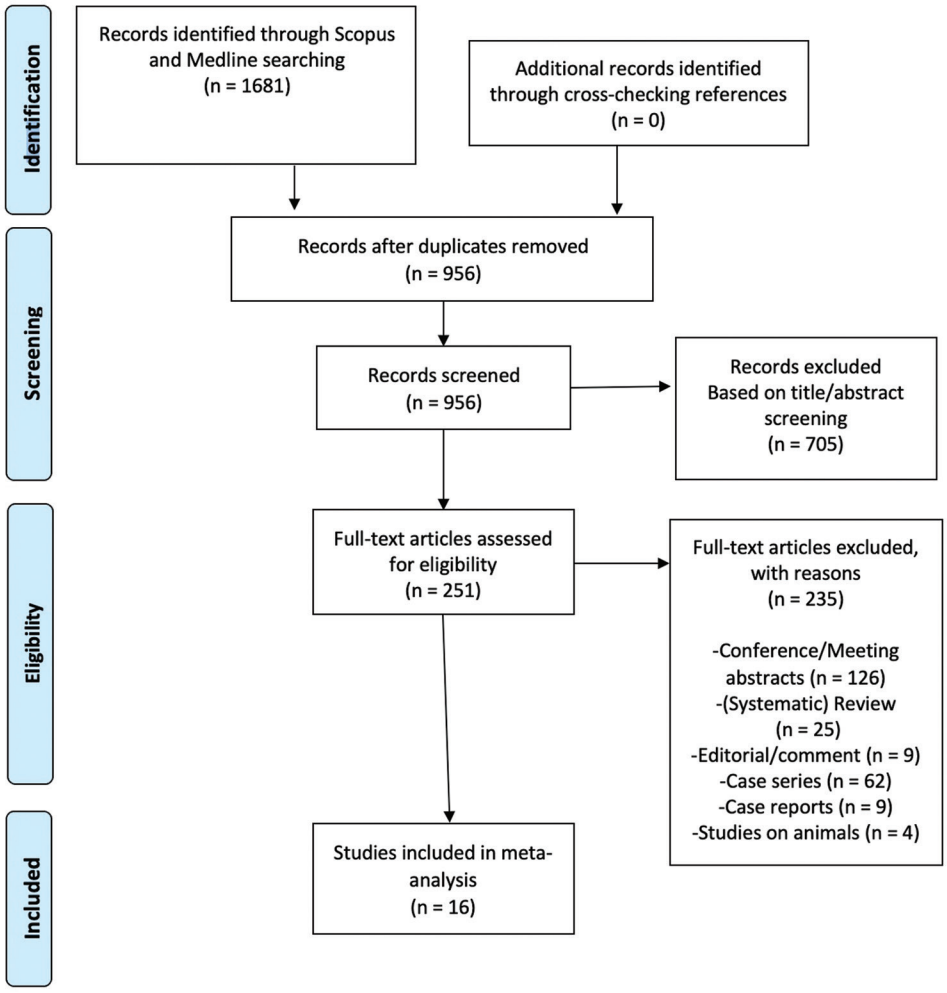
Study	Country	Year	*n*	RAKT (*n*)	OKT (*n*)	Study Design	Age	Gender (male/female)	BMI	Living/ deceased donor	Time on dialysis	Cooling method	Immunosuppressant
Ahlawat *et al*.	USA / India	2021	653	126	528	Prospective cohort	RAKT: 40 (30–50); OKT: 41 (30–51)	RAKT: 101/25; OKT: 310/68	BMI *per* category: 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	All donors were living donors	RAKT: 62.5 days (16.5–151.5); OKT: 63.5 (17–157.5)	Cold ringer lactate perfusion and packing in ice slush	Induction with ATG or Basiliximab
Bansal *et al*.	India	2020	25	4	21	Retrospective cohort	OKT–16 (15–17); RKT–16 (15.5–16.25), *P* – 0.88	OKT: 17/4; RKT: 2/2. *P* – 0.23	OKT–18 (16–21); RKT–19 (17.25–20.50), *P* – 0.04	All donors were living donors	NR	Perfusion with cold HTK solution and packing in ice slush	NR
Campi *et al*.	Italy	2022	138	21	117	Prospective cohort	OKT: 48 (42–58); RAKT: 46 (36–54). *P* – 0.2	OKT: 70/47; RAKT: 11/10. *P* – 0.5	OKT: 23.4 (21.6–26.6); RAKT: 23.5 (21.4–26). *P* – 0.7	All donors were deceased donors	OKT: 32 months (16.0–54.0); RAKT: 9 (0–24.0). *P*–<0.001	NR	NR
Eksi *et al*.	Turkey	2021	127	60	67	Prospective cohort	RAKT: 37.5±10.4 OKT: 43.9±11.8 *P* – 0.002	Total: 82/45	OKT: 24.8±2.1; RAKT: 23.9±3.5 *P* – 0.08	All donors were living donors	NR	NR	Induction with ATG in high risk. Maintenance with prednisone, mycophenolate mofetil, and tacrolimus
Garcia-Roca *et al*.	USA	2016	612	67	545	Retrospective cohort	RAKT: 46.4±10.7 OKT: 48.1±12.5 *P* – 0.28	RAKT: 32/35 OKT: 281/264 *P* – 0.18	BMI *per* category: *P* – 0.701 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	All donors were living donors	RAKT: 49.1±38.1 months OKT: 47.1±43.4 *P* – 0.701	NR	Induction with ATG/ basiliximab/Campath/ rituximab/OKT3. Maintenance with steroids/CNI/MMF
Karadag *et al*.	Turkey	2022	189	91	98	Retrospective cohort	RAKT: 37.3±10.6; OKT: 43.5±11.4; *P* – <0.0001	No significant difference between OKT and RAKT groups	RAKT: 23.9±3.3; OKT: 24.4±2.1, *P* – 0.215	All donors were living donors	NR	NR	Induction with ATG in high risk. Maintenance with prednisone, mycophenolate mofetil, and tacrolimus
Kishore *et al*.	India	2019	36	18	18	Retrospective cohort	RAKT: 37.1±13.2; OKT: 35.2±12.8, *P* – 0.7536	RAKT: 13/5; OKT: 14/4, *P* – 1.0	RAKT: 26.6±3.1; OKT: 24.9±3.18, *P* – 0.268	All donors were living donors	NR	NR	NR

Contd...

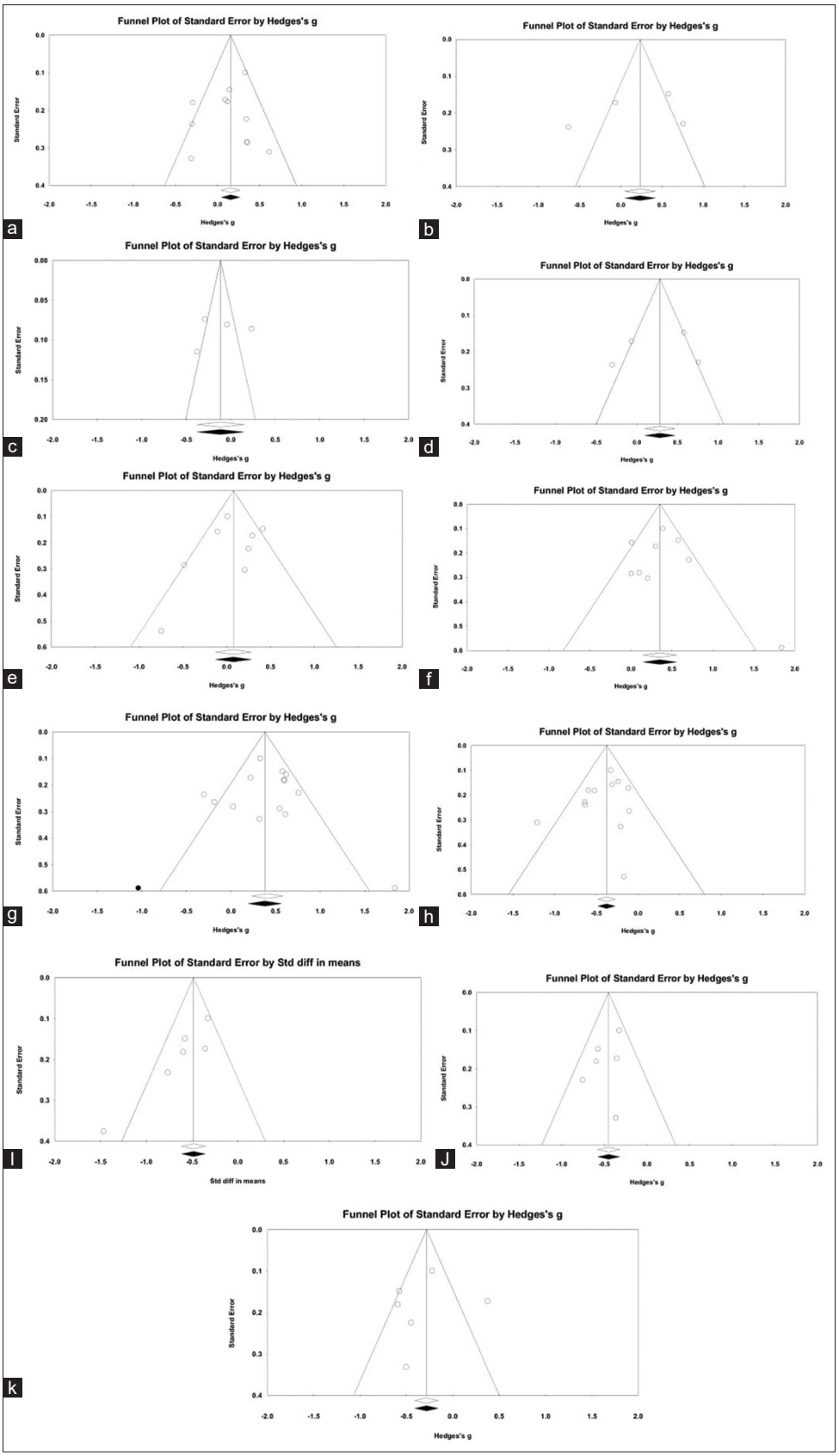
Supplemental Table 2: Contd...

Study	Country	Year	*n*	RAKT (*n*)	OKT (*n*)	Study Design	Age	Gender (male/female)	BMI	Living/ deceased donor	Time on dialysis	Cooling method	Immunosuppressant
Lee *et al.*	USA	2021	48	24	24	Prospective cohort	RAKT: 51.21±11.9; OKT: 56.29±11.9, *P*– 0.15	RAKT: 14/10; OKT: 9/15; *P* – 0.15	RAKT: 40.1 (35–49); OKT: 38.5 (35–44), *P* – 0.078	RAKT: 9/15; OKT: 6/18, *P* – 0.55	RAKT: 48.1±34.5 months; OKT: 50.7±38.5, *P* – 0.81	NR	Induction with ATG followed by steroids, mycophenolate mofetil, and tacrolimus
Maheshwari *et al.*	India	2020	207	55	152	Prospective cohort	RAKT: 40.7±13.9; OKT: 42.5±11.9, *P* – 0.781	RAKT: 42/13; OKT: 122/30, *P* – 0.542	RAKT: 26.2±6.9; OKT: 24.35±5.0, *P* – 0.066	All donors were living donors	RAKT: 10.77±8.42 months; OKT: 3.85±3.56, *P*<0.001	Perfusion with cold HTK solution and packing in ice slush	Induction with ATG or Basiliximab
Nataraj *et al.*	India	2020	86	43	43	Retrospective cohort	RAKT: 40.3±13.4; OKT: 42±15, *P* – 0.8	RAKT: 30/13; OKT: 27/16, *P* – 0.2	RAKT: 26.8±4.2; OKT: 22.6±4.4, *P* – 0.05	All donors were living donors	RAKT: 300 days (20–470); OKT: 290 (22–360), *P* – 0.9	NR	Induction with ATG/ Basiliximab in high risk. Maintenance with prednisone, mycophenolate mofetil, and tacrolimus
Pein *et al.*	Germany	2019	42	21	21	Prospective cohort	RAKT: 48.0±10.3; 44.6± (26–64)	RAKT: 16/5; OKT: 10/11	RAKT: 25.5±4.1; OKT: 26.4±5.7	All donors were living donors	RAKT: 1.4±1.9 years; OKT: 1.3±2.1	NR	NR
Territo *et al.*	Spain	2021	49	25	24	Prospective cohort	RAKT: 49±14; OKT: 53±15, *P* – 0.71	RAKT: 67%/33%; OKT: 65/35%, *P* – 0.90	RAKT: 25±4; OKT: 25±4, *P* – 0.95	All donors were living donors	NR	NR	NR
Tinney *et al.*	USA	2022	94	47	47	Retrospective cohort	RAKT: 48 (36–60); OKT: 50 (40–60), *P* – 0.60	RAKT: 31/16; OKT: 31/16, *P* – 1.0	RAKT: 29.6 (25.0–33.6); OKT: 28.4 (24.4–34.2), *P* – 0.96	All donors were living donors	RAKT: 24 months (9–32); OKT: 14 (7–25), *P* – 0.39	NR	Induction with ATG or Basiliximab
Tugcu *et al.*	Turkey	2017	80	40	40	Prospective cohort	RAKT: 37.67±11.28; OKT: 42.45±13.74, *P* – 0.093	RAKT: 25/15; OKT: 28/12	RAKT: 23.2±3.29; OKT: 25.3±2.17, *P* – 0.001	All donors were living donors	NR	NR	NR
Spaggiari-Oberholzer *et al.*	USA	2013–2018	56	28	28	Prospective cohort	RAKT: 47.9±10.7; OKT: 49.8±10.8, *P* – 0.51	RAKT: 13/15; OKT: 11/17, *P* – 0.59	RAKT: 42.6±7.8; OKT: 38.1±10.8, *P* – 0.02	RAKT: 26/2; OKT: 26/2	RAKT: 32.0±34.7; OKT: 15.6±11.8, *P* – 0.08	NR	Induction with ATG in high risk. Maintenance with steroids, mycophenolate mofetil, and tacrolimus. Desensitization with plasmapheresis and IVIG

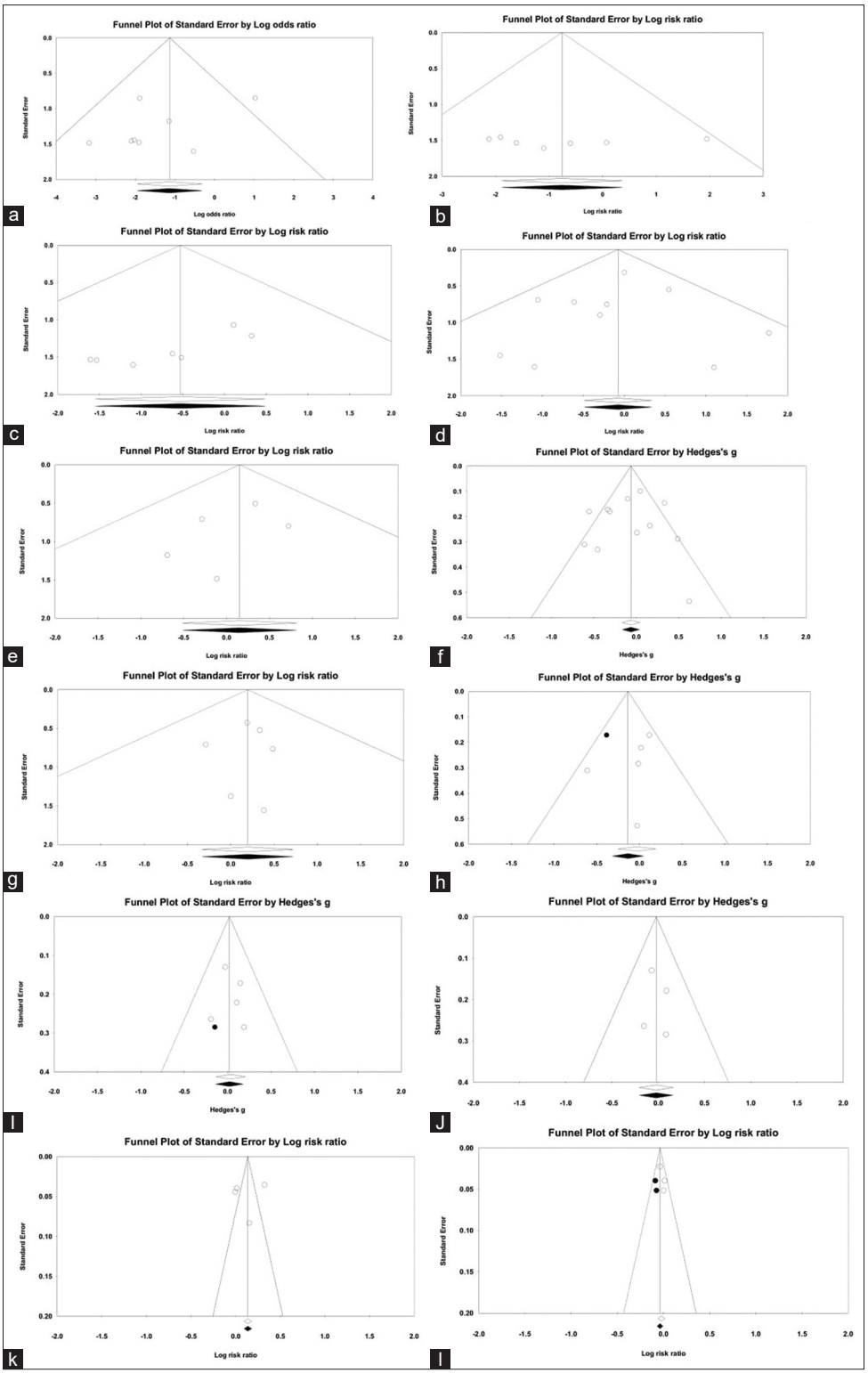
OKT=Open kidney transplant, RAKT=Robot assisted kidney transplant, BMI=Body mass index, NR - not recorded,ATG - Anti-thymocyte globulin,CNI - Calcineurin inhibitor,MMF - Mycophenolate mofetil, IVIg - Intravenous immunoglobulin, HTK - Histidine-tryptophan-ketoglutarate



Supplemental Figure S1: Flow chart of assessing evidence following PRISMA guidelines. PRISMA: Preferred Reporting Items for Systematic Review and Meta-Analysis



Supplemental Figure S2: Funnels plots showing publication bias for (S2a) Operative time, (S2b) arterial anastomosis time, (S2c) venous anastomosis time, (S2d) ureterovesical anastomosis time, (S2e) warm ischemia time, (S2f) cold ischemia time, (S2g) rewarming time, (S2h) blood loss, (S2i) incision length, (S2j) pain scores at 24 h, (S2k) pain scores at 48 h



Supplemental Figure S3: Funnels plots showing publication bias for (S3a) SSIs, (S3b) lymphocele formation, (S3c) graft thrombosis and ureter related complications, (S3d) delayed graft function, (S3e) postoperative UTIs, (S3f) length of hospital stay, (S3g) events of acute rejection, (S3h) serum creatinine at 30 days postop, (S3i) serum creatinine at 180 days postop, (S3j) serum creatinine at 1 year postop, (S3k) graft survival and (S3l) overall survival.