Research Square

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Comparative Effectiveness of Open, Laparoscopic, and Robot-Assisted Kasai Portoenterostomy for Biliary Atresia: A Network Meta-Analysis

Yiduo Xiong
Capital Medical University
Kai Wang
wangkai0000shouyi@163.com
Beijing Children's Hospital

Research Article

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Abstract

Objective

To provide an updated comparison of open Kasai portoenterostomy (OKPE), laparoscopic Kasai portoenterostomy (LKPE), and robot-assisted Kasai portoenterostomy (RAKPE), and to evaluate the relative efficacy and safety of robotic-assisted surgery within the current minimally invasive landscape.

Methods

Following PRISMA guidelines, studies evaluating surgical techniques of Kasai portoenterostomy (KPE) for BA were systematically searched, and those enrolling OKPE, LKPE, or RAKPE, and directly comparing at least two techniques were included. Network meta-analysis was conducted using the “gemtc” package in R (version 4.3.3), and pairwise meta-analyses were performed for outcomes without a connected evidence network.

Results

Twenty-seven studies comprising 2,030 patients were included. Compared with LKPE, OKPE had shorter operative time (MD = 49.32 min, 95% CI: 33.44–65.25), and lower blood loss (MD = − 8.25 mL, 95% CI: − 14.00 to − 2.51). Whereas, LKPE showed shorter hospital stay compared with OKPE (SMD=-0.29, 95%CI: -0.60-0.01), although the difference did not reach statistical significance. In addition, RAKPE did not differ from OKPE or LKPE in operative time or intraoperative blood loss. RAKPE demonstrated the highest jaundice clearance rates at both 3 and 6 months postoperatively, but the between-group differences remained statistically non-significant.Patients showed similar rate either for 1-year native liver survival or postoperative cholangitis for the three approaches. Postoperative ALT and TBIL levels at 1, 3, and 6 months had no difference between OKPE and LKPE.

Conclusion

OKPE, LKPE, and RAKPE showed comparable outcomes. OKPE has advantages in shortening operative time and reducing intraoperative blood loss, while LKPE has the fastest postoperative recovery, and RAKPE demonstrated favorable numerical trends in jaundice clearance.

1. Introduction

Biliary atresia (BA) affected approximately 1 in 5000–15000 live-born infants[1]. It is a serious hepatobiliary disease, characterized as progressive inflammation and fibrosis of extrahepatic and intrahepatic bile ducts. Left untreated, it will lead to severe biliary cirrhosis and cause end-stage liver disease within 2 years, constituting the main reason for children liver transplantation. Kasai

portoenterostomy, which aimed at restoring bile drainage to delay the process of liver fibrosis, is recommended as the first-line treatment[2]. Recently, laparoscopic Kasai portoenterostomy (LKPE) [3]and robot-assisted Kasai portoenterostomy (RAKPE)[4] have gradually been brought into use as minimally invasive alternatives to open Kasai portoenterostomy (OKPE). However, results among these approaches remain limited, and available studies have produced inconsistent findings because of differences in study design, sample size, outcome definitions, and follow-up duration.

Although previous meta-analyses have compared different Kasai techniques, the rapid accumulation of RAKPE studies in recent years has changed the landscape of minimally invasive surgery for biliary atresia. An updated synthesis incorporating emerging robotic evidence is therefore required to clarify the comparative position of RAKPE among currently available surgical approaches. Moreover, previous analyses have mainly focused on pairwise comparisons, limiting comprehensive evaluation of the relative efficacy among all available surgical approaches. Therefore, this network meta-analysis was performed to integrate direct and indirect evidence and provide a comparative assessment of OKPE, LKPE, and RAKPE for BA patients.

2. Methods

2.1 Literature Search Strategy

Studies comparing OKPE, LKPE, and RAKPE from its beginning through July 2025 were searched on PubMed, Embase, Web of Science, and the Cochrane Library. The study used both controlled vocabulary and free-text terms related to biliary atresia, BA, Kasai portoenterostomy, hepatic portoenterostomy, open surgery, laparoscopy, robotic surgery, and Da Vinci. The search and screening process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.2 Inclusion and Exclusion Criteria

The study included randomized controlled trials and observational cohort studies, either prospective or retrospective, involving BA patients who underwent Kasai portoenterostomy. There were no restrictions on age, sex, or nationality. A study had to directly compare at least two of the three surgical techniques and report at least one relevant outcome. These outcomes could include operative time, blood loss, hospital stay, jaundice clearance, cholangitis, overall complications, or native liver survival.

The study excluded case reports, case series, reviews, commentaries, conference abstracts, and basic science studies. Duplicate publications were handled by keeping the most complete or the most recent report. The study also excluded articles not written in English or Chinese, studies without accessible full text, studies with missing or unusable data, and studies judged to have major methodological problems.

2.3 Data Extraction and Quality Assessment

Two reviewers independently screened the literature and extracted data using EndNote X9. Any disagreement was resolved through discussion with a third reviewer, who was a senior pediatric

surgeon. The extracted information included first author, publication year, sample size, surgical method, age at surgery, operative time, blood loss, hospital stay, jaundice clearance time and rate, cholangitis rate, and native liver survival. Preoperative clinical variables, including preoperative total bilirubin levels, BA type, and fibrosis-related parameters, were also screened. However, these variables were inconsistently reported and therefore could not be quantitatively analyzed.

2.4 Risk of Bias Assessment

Overall, most included studies were assessed to have a moderate to high risk of bias, mainly due to retrospective design, limited blinding, and incomplete reporting of outcome assessment.

2.5 Statistical Analysis

The study used Stata 17.0 and R software with the gemTC package to build the network plots and calculate SUCRA values. First, inconsistency was tested. For closed loops, the node-splitting method was used to compare direct and indirect evidence. When the inconsistency test showed $P > 0.05$, a consistency model was applied. For continuous outcomes measured on different scales, such as operative time and blood loss, standardized mean difference with 95% confidence intervals was used. Publication bias was checked with comparison-adjusted funnel plots. Finally, the three surgical techniques were ranked using SUCRA values, with a higher value indicating a greater chance of being the best option for that outcome.

3. Results

A total of 27 studies were included in the analysis, comprising 2,030 BA patients (Fig. 1). Most included studies were assessed to have a moderate to high risk of bias, mainly due to retrospective design, limited blinding, and incomplete reporting of outcome assessment. Operative time, intraoperative blood loss, length of hospital stay, postoperative jaundice clearance rates at 3 and 6 month, alanine aminotransferase (ALT) and total bilirubin (TBIL) levels at 1, 3, and 6 months, cholangitis rates at 3 months, and 1-year native liver survival were extracted (Table S1). Baseline characteristics of included studies are summarized in Supplementary Table S1. However, the availability of individual outcomes varied substantially among studies. While operative characteristics were relatively well reported, postoperative biochemical outcomes and long-term prognostic indicators were limited, particularly for RAKPE.

3.1 General Characteristics

Figure 2A depicts a closed triangular network of treatment comparisons, facilitating direct and indirect evidence assessment. The line thickness between nodes signifies the number of comparative studies, with greater thickness indicating a higher study volume. For all outcome indicators within this closed loop, the node-splitting method showed no significant inconsistency between direct and indirect evidence ($P > 0.05$). Therefore, a consistency model was employed for all network meta-analyses.

3.2 Age at Surgery

Twenty-six studies had this data and network meta-analysis results showed that 95% confidence intervals (CIs) for all pairwise comparisons crossed zero, indicating that none of the pairwise comparisons in age at surgery reached statistical significance among the three technique groups. Compared with LKPE, the mean age at surgery in the OKPE group differed by 0.22 days (95% CI: −1.45 to 1.89), while the RAKPE group differed by 2.46 days (95% CI: −0.53 to 5.46). The comparison between RAKPE and OKPE also showed no significant difference (MD = 2.25 days, 95% CI: −0.96 to 5.45), as all confidence intervals crossed zero. The SUCRA ranking (Fig. 2B-D) suggested a probability ranking from youngest to oldest age as RAKPE > LKPE > OKPE, indicating that patients undergoing RAKPE tended to have a younger age at surgery, although the intergroup differences in age at surgery did not achieve statistical significance. However, as this ranking lacks statistical support, it suggests that the timing of surgery is not influenced by the choice of surgical technique.

3.3 Operative Time

Twenty studies reported operative time, and network meta-analysis was performed to compare operative duration among OKPE, LKPE, and RAKPE. Network meta-analysis revealed that compared with OKPE, both LKPE and RAKPE was associated with a longer operative time (LKPE: MD = 49.32 minutes, 95% CI: 33.44 to 65.25, $P < 0.05$; RAKPE: MD = 22.91 minutes, 95% CI: -12.02 to 57.61, $P > 0.05$). RAKPE and LKPE (MD = -26.41 minutes, 95% CI: -64.86 to 11.87, $P > 0.05$) also showed comparable operative durations. SUCRA ranking analysis indicated that OKPE had the highest probability of ranking favorably for shorter operative time, followed by RAKPE and LKPE. However, these rankings should be interpreted cautiously because SUCRA values represent relative probabilities rather than definitive evidence of clinical superiority.

3.4 Intraoperative Blood Loss

A total of 17 studies provided data on intraoperative blood loss. Network meta-analysis showed that OKPE was associated with significantly less blood loss than LKPE (MD = -8.25 mL, 95% CI: -14.00 to -2.51, $P < 0.001$). There was no significant difference between OKPE and RAKPE (MD = -5.52 mL, 95% CI: -13.66 to 2.61, $P > 0.05$) or between RAKPE and LKPE (MD = -2.73 mL, 95% CI: -6.44 to 11.89, $P > 0.05$). SUCRA ranking (Fig. 2E-G) suggested that OKPE had the highest probability of being the technique with the least blood loss, followed by RAKPE and LKPE.

3.5 Length of hospital Stay

16 studies was available for this analysis. Due to data limitations, only comparisons between OKPE and LKPE, and between OKPE and RAKPE were possible. The network meta-analysis (Fig. 3A-B) showed that LKPE was associated with a shorter hospital stay compared with OKPE (SMD = -0.29, 95% CI: -0.60 to 0.01), although the difference did not reach statistical significance. The comparison between OKPE and RAKPE suggested a similar hospital stay (SMD = 0.50, 95% CI: -0.27 to 1.26).

3.6 Postoperative ALT Levels

ALT levels at 1, 3, and 6 months were reported in seven studies. Traditional meta-analysis (Fig. 4A-C) showed no statistically significant difference in ALT levels between OKPE and LKPE at 1 month (SMD = -0.26, 95% CI: -0.52 to 0.00, P > 0.05) or 3 months (SMD = -0.04, 95% CI: -0.29 to 0.21, P > 0.05). At 6 months (SMD = 0.23, 95% CI: -0.50 to 0.96), the confidence interval crossed zero and heterogeneity was high (I^2 = 89.6%), indicating substantial heterogeneity across studies (I^2 = 89.6%) and limiting the reliability of the combined estimate.

3.7 Postoperative TBIL Levels

Seven studies contributed data on postoperative total bilirubin (TBIL) levels at 1, 3, and 6 months. levels at 1, 3, and 6 months postoperatively, all comparing OKPE and LKPE. Traditional meta-analysis (Fig. 4D-F) showed that at 1 month (SMD = -0.67, 95% CI: -3.14 to 0.79), 3 months (SMD = -0.88, 95% CI: -3.82 to 1.05), and 6 months (SMD = -0.86, 95% CI: -3.52 to 0.80), the confidence intervals all crossed zero, and heterogeneity was extremely high (I^2 > 97%). This indicates substantial variability between studies and instability of the results, precluding any definitive conclusions.

3.8 Postoperative Jaundice Clearance Rate

Jaundice clearance rates at 3 and 6 months were reported in 22 studies. Pooled effect sizes (Fig. 3C-H) showed that at 3 months postoperatively, the RAKPE group had the highest jaundice clearance rate (ES = 0.780, 95% CI: 0.698 to 0.841), followed by OKPE (ES = 0.663, 95% CI: 0.572 to 0.754) and LKPE (ES = 0.561, 95% CI: 0.405 to 0.717). This ranking remained consistent at 6 months: RAKPE (ES = 0.734, 95% CI: 0.627 to 0.841), OKPE (ES = 0.668, 95% CI: 0.580 to 0.756), and LKPE (ES = 0.592, 95% CI: 0.481 to 0.703). The 3-month jaundice clearance rate was lowest in the LKPE group. While RAKPE showed the numerically highest rates, the differences were not always statistically significant. Although RAKPE demonstrated numerically higher jaundice clearance rates at both 3 and 6 months postoperatively, these findings did not reach statistical significance. Therefore, the potential advantage of RAKPE requires further validation in larger comparative studies.

3.9 Three-Month Postoperative Cholangitis Rate

Postoperative cholangitis was reported in 19 studies, although follow-up time points varied considerably across studies. For consistency, 3-month postoperative cholangitis data from four studies were selected, all comparing OKPE and LKPE. Pooled results (Fig. 5A-B) showed that the estimated cholangitis rate was 24.6% (95% CI: 6.6% to 43.7%) for LKPE and 25.6% (95% CI: 5.8% to 45.4%) for OKPE. The confidence intervals were wide and heterogeneity was substantial (I^2 > 90%), suggesting considerable variability across studies. Although the estimated cholangitis rates were similar between LKPE and OKPE, the current evidence was insufficient to establish a reliable difference in 3-month postoperative cholangitis rates.

3.10 One-Year Native Liver Survival Rate

Native liver survival outcomes were available in 16 studies. To ensure uniformity, the 1-year native liver survival rate, which had the largest sample size, was selected from seven studies, all comparing OKPE

and LKPE. Pooled results (Fig. 5C-D) showed that the native liver survival rate was 69.0% (95% CI: 58.7% to 79.3%) for LKPE and 69.4% (95% CI: 64.1% to 74.7%) for OKPE, with no difference. Heterogeneity was low for the OKPE group (I^2 = 21.3%) and moderate for the LKPE group (I^2 = 66.3%), suggesting that the overall results are relatively reliable and that the two techniques have comparable efficacy in terms of 1-year native liver survival.

4. Discussion

Previous studies have summarized outcomes of different Kasai techniques; however, most available evidence was based on comparisons between OKPE and LKPE. With the introduction of RAKPE and increasing reports from high-volume centers, the comparative effectiveness of robotic surgery requires further clarification. This network meta-analysis incorporated recent robotic cohorts and provided a comprehensive comparison among OKPE, LKPE, and RAKPE.

Network meta-analysis evaluated the efficacy and safety of OKPE, LKPE, and RAKPE in 2030 BA patients from 27 studies. Due to the potential advantages of reduced surgical trauma, less postoperative pain, and faster recovery, minimally invasive approaches have gained increasing attention. However, ongoing disputes persist, as some studies indicate a high incidence of postoperative cholangitis or a low native liver survival rate. Therefore, the perioperative characteristics and long-term outcomes of these three techniques should be compared to find out their respective advantages and limitations. The comparative advantages of each technique varied according to individual clinical outcomes. Although network meta-analysis allows simultaneous comparison of multiple interventions, the interpretation of the findings should consider the limitations of the available evidence, including the predominance of retrospective studies, variation in outcome definitions, and the limited number of studies evaluating RAKPE.

Baseline analysis showed that there was no significant difference in age at operation among the three groups, which indicated that the timing of Kasai portoenterostomy mainly depended on the diagnosis and referral situation rather than the surgical technique. Early Kasai portoenterostomy is widely accepted[32]. Research reports pointed out that the earlier the operation is performed at a younger age, the better the bile drainage and the prognosis of the liver will be[33]. Although infants with late presentation often have more severe liver enlargement and relatively less abdominal space, which may increase the technical complexity and limit the view of minimally invasive surgery. At this time, OKPE is still technically reliable because the open surgery has stable experience and helps to completely remove the fibrous plate at the portohepatic hilum.

RAKPE improves surgical precision with high-definition 3D vision, tremor filtering, and articulating instruments[34]. Our pooled analysis showed that OKPE significantly less blood loss than LKPE, while RAKPE demonstrated lower blood loss than LKPE but without statistical significance, indicating a trend rather than a definitive advantage.This pattern may be explained by improved visualization of hilar vessels and enhanced instrument articulation, which may facilitate precise dissection and hemostasis while reducing inadvertent injury to small portal venous branches[35].

The clearance of jaundice is a key efficacy indicator of the Kasai procedure, which is usually evaluated by TBIL in the post-operative period. Limited by data constraints, sufficient TBIL values for RAKPE were not available in the included studies; therefore, the present analysis directly utilized the reported jaundice clearance rates for statistical evaluation. The visualization of the robot helps to better locate the micro-bile ducts in the porta hepatis and resect the fibrotic tissue, thus helping bile drainage. In the Network meta-analysis, the 3-month and 6-month jaundice clearance rates of RAKPE are the highest, although it is not always statistically significant. The SUCRA ranking shows that RAKPE may be beneficial for jaundice clearance. The research results are in line with the situation that better vision and instrument dexterity may help porta hepatis anatomy, but the existing evidence is not sufficient to confirm its superiority[36].

RAKPE usually has a longer operation time[4]. Previously, it was reported that the robot surgery cohort had an extended time due to docking, setup, and early adoption. The evidence regarding the survival of the native liver and cholangitis after RAKPE is relatively limited. So, RAKPE-related long-term outcomes could not be robustly quantified in the present pooled analysis. Available reports have suggested that native liver survival after RAKPE may be comparable to that after OKPE; however, these findings remain preliminary and should be interpreted cautiously. Similarly, published studies have reported variable postoperative cholangitis rates after RAKPE. Postoperative cholangitis is caused by multiple factors, and surgical technique alone may not be able to fully determine it. In the present analysis, no significant difference in hospital stay was observed between RAKPE and OKPE, suggesting that any recovery advantage of RAKPE remains uncertain and may depend on perioperative management and institutional pathways. Therefore, the potential recovery benefit of RAKPE should be interpreted cautiously and should not be overstated based on the current evidence.

RAKPE has made certain progress in terms of vision and ergonomics, but in many pediatric surgery centers, LKPE is still the most commonly used minimally invasive technique. In this analysis, the hospital stay after LKPE is shorter than that after OKPE, which supports the recovery advantage of the minimally invasive approach. Earlier mobilization, fewer wound traumas, and faster resumption of oral intake may contribute to this advantage, but the intraoperative effect of LKPE is not satisfactory, especially in terms of operating time. As reported by Li et al., operative time was longer in the laparoscopic cohort[37]. Shirota et al. also reported a significantly longer operative time compared with OKPE[27]. This may be because laparoscopy has limitations, such as limited field of view, less tactile feedback, relying on two-dimensional images, etc., which hinder precise hilar dissection.

There are different situations of blood loss in LKPE research, maybe because of the different experience of surgeons and intraoperative strategies. Some reports point out that the hemostasis in the laparoscopic group is acceptable, but the use of electrocautery may increase the risk of thermal injury to the portal structure, thereby affecting the patency of the biliary duct and the post operative bile drainage[30]. In this analysis, the jaundice clearance rate after LKPE is lower than that of OKPE and RAKPE. Some studies claim that the jaundice clearance rates of LKPE and OKPE are roughly similar, but

the results are related to technical improvement and surgeon experience. This difference indicates that LKPEE has a steep learning curve, which limits the reproducibility of different centers[38].

5 Limitations

This analysis has several limitations. First, most included studies were retrospective cohort studies, and only one study reported randomization, with none describing allocation concealment, which may introduce selection bias. Second, substantial heterogeneity was observed in several outcome measures, particularly postoperative ALT and TBIL levels, likely reflecting differences in surgical techniques, perioperative management, follow-up intervals, and laboratory assessment methods among centers. Third, the evidence regarding RAKPE remains limited because of the small number of available studies, relatively small sample sizes, and insufficient long-term follow-up data. In addition, learning-curve effects associated with minimally invasive procedures were not fully evaluated, although previous studies have suggested that operative performance may improve with increasing surgical experience. Furthermore, although network meta-analysis and SUCRA ranking provide a framework for comparing multiple surgical approaches, these statistical methods cannot compensate for limitations in the underlying evidence. Therefore, the ranking results should be considered exploratory rather than definitive. Finally, SUCRA values were calculated to provide probabilistic rankings of the three surgical techniques for each outcome. Higher SUCRA values indicate a greater probability of ranking higher for a specific outcome; however, these rankings were interpreted together with effect estimates and confidence intervals rather than as evidence of definitive superiority.

Future multicenter prospective studies with standardized inclusion criteria, surgical protocols, and outcome definitions are required to further clarify the comparative effectiveness of different Kasai approaches. Additional investigations focusing on long-term outcomes, cost-effectiveness, and subgroup analyses according to age at surgery, pathological characteristics, and degree of liver fibrosis may help identify the optimal surgical strategy for individual BA patients.

6 Conclusion

This network meta-analysis suggests that OKPE, LKPE, and RAKPE provide comparable overall outcomes for patients with biliary atresia, with no approach demonstrating statistically significant superiority across major prognostic indicators. OKPE remains advantageous regarding operative efficiency and intraoperative blood loss. LKPE may provide benefits in postoperative recovery, particularly in reducing hospital stay. RAKPE demonstrates favorable trends in jaundice clearance; however, further high-quality studies are required to confirm its potential advantages.

Declarations

Author Contribution

Author Contribution StatementY.X. contributed to the study conception and design, literature search and screening, data extraction, statistical analysis, interpretation of the results, and drafting of the manuscript. K.W. contributed to the study conception and design, supervision of the study, interpretation of the results, and critical revision of the manuscript for important intellectual content. Both authors reviewed and approved the final manuscript and agreed to be accountable for all aspects of the work.

Data Availability

Data Availability StatementAll data analyzed in this network meta-analysis were derived from previously published and publicly available studies. The data supporting the findings of this study are available from the original publications and their supplementary materials, where applicable.

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Figures

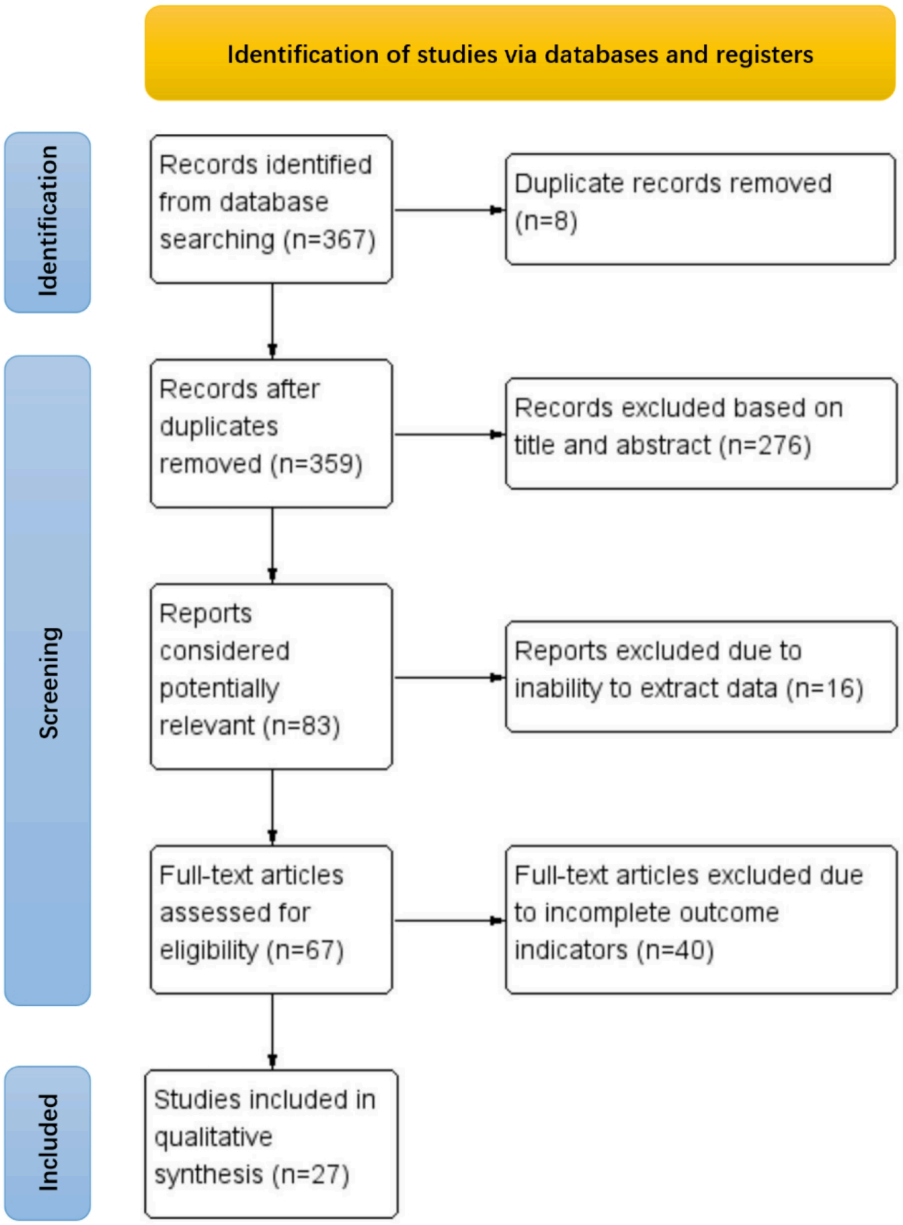


Figure 1

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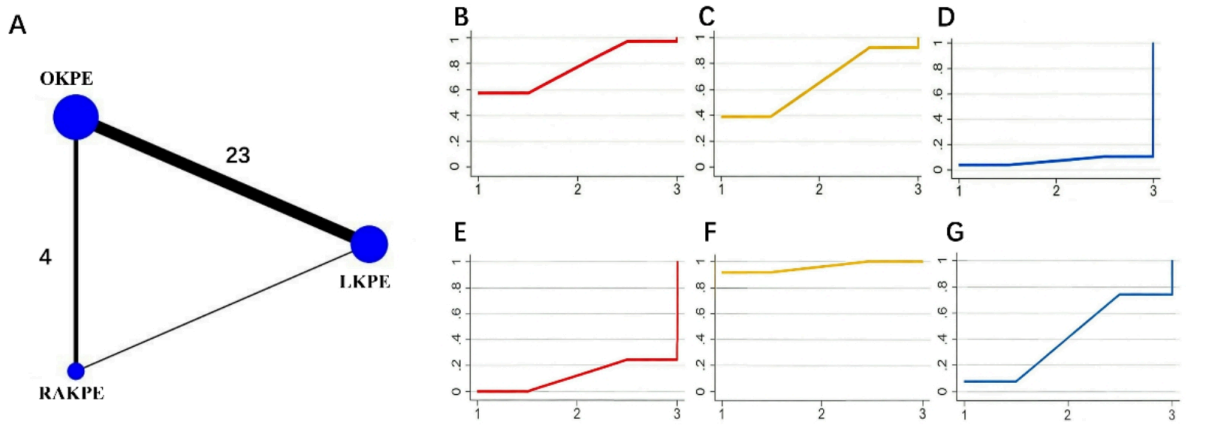


Figure 2.(A) Network evidence diagram of the included studies comparing OKPE, LKPE, and RAKPE; Cumulative probability plot of age at surgery among the three procedures (B) LKPE (C) OKPE (D) RAKPE; Cumulative probability plot for amount of bleeding among the three procedures (E) LKPE (F) OKPE (G) RAKPE

Figure 2

See image above for figure legend.

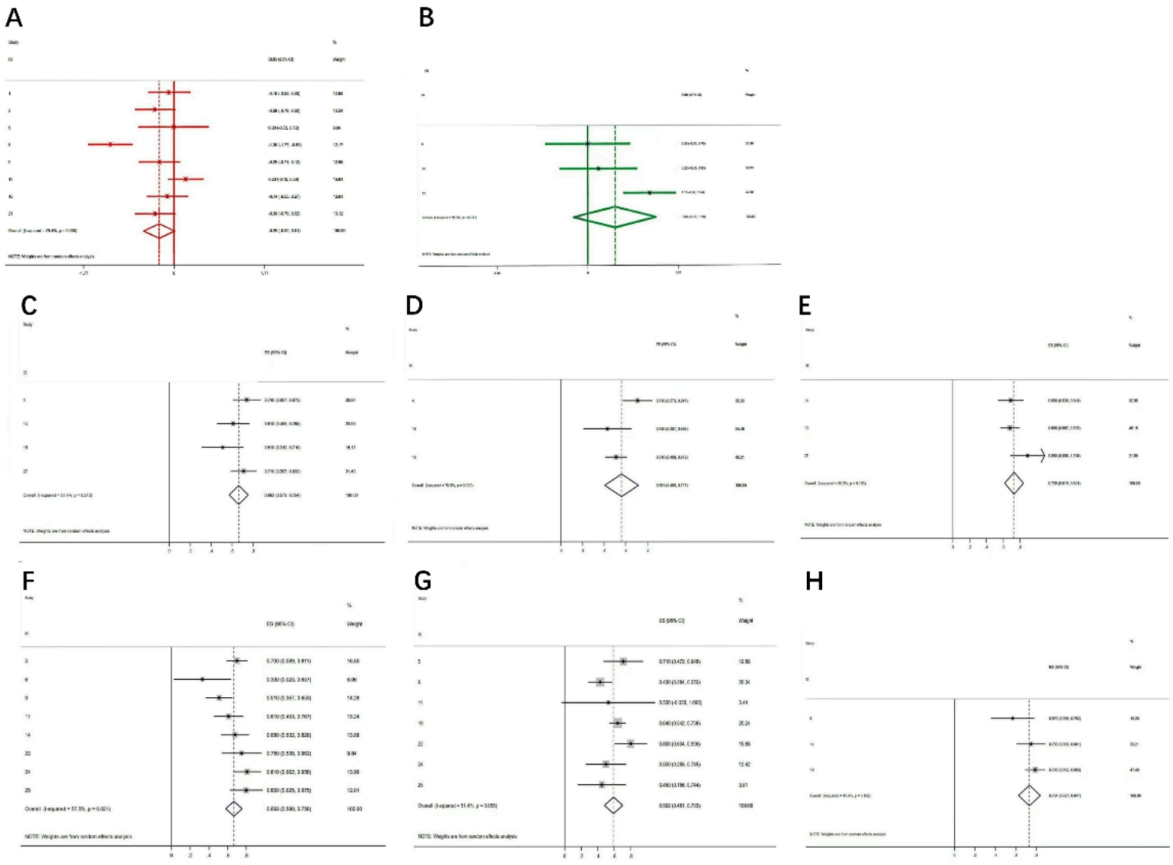


Figure 3. Forest plot for hospital stays comparing OKP with LKP (A) and Da Vinci (B); removal rate of jaundice in patients undergoing OKP, LKP, and Da Vinci at 3 and 6 months postoperatively (C) OKP at 3 months (D) LKP at 3 months (E) Da Vinci at 3 months (F) OKP at 6 months (G) LKP at 6 months (H) Da Vinci at 6 months

Figure 3

See image above for figure legend.

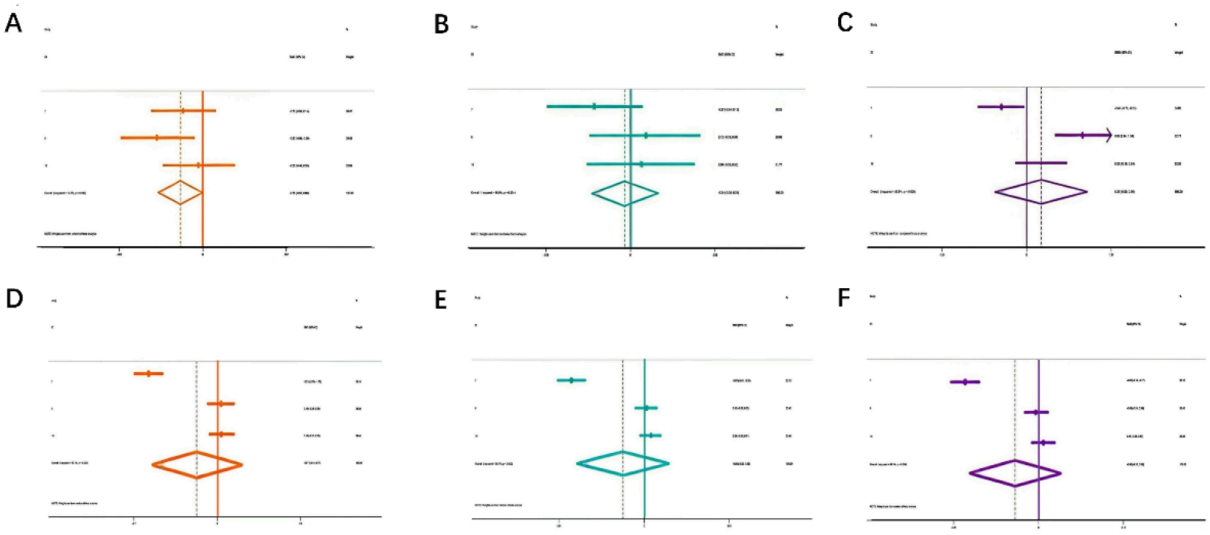


Figure 4. Forest plots of postoperative ALT and TBIL levels between OKPE and LKPE (A) ALT at 1 month postoperatively (B) ALT at 3 month postoperatively (C) ALT at 6 month postoperatively (D) TBil at 1 month postoperatively (E) TBil at 3 month postoperatively (F) TBil at 6 month postoperatively

Figure 4

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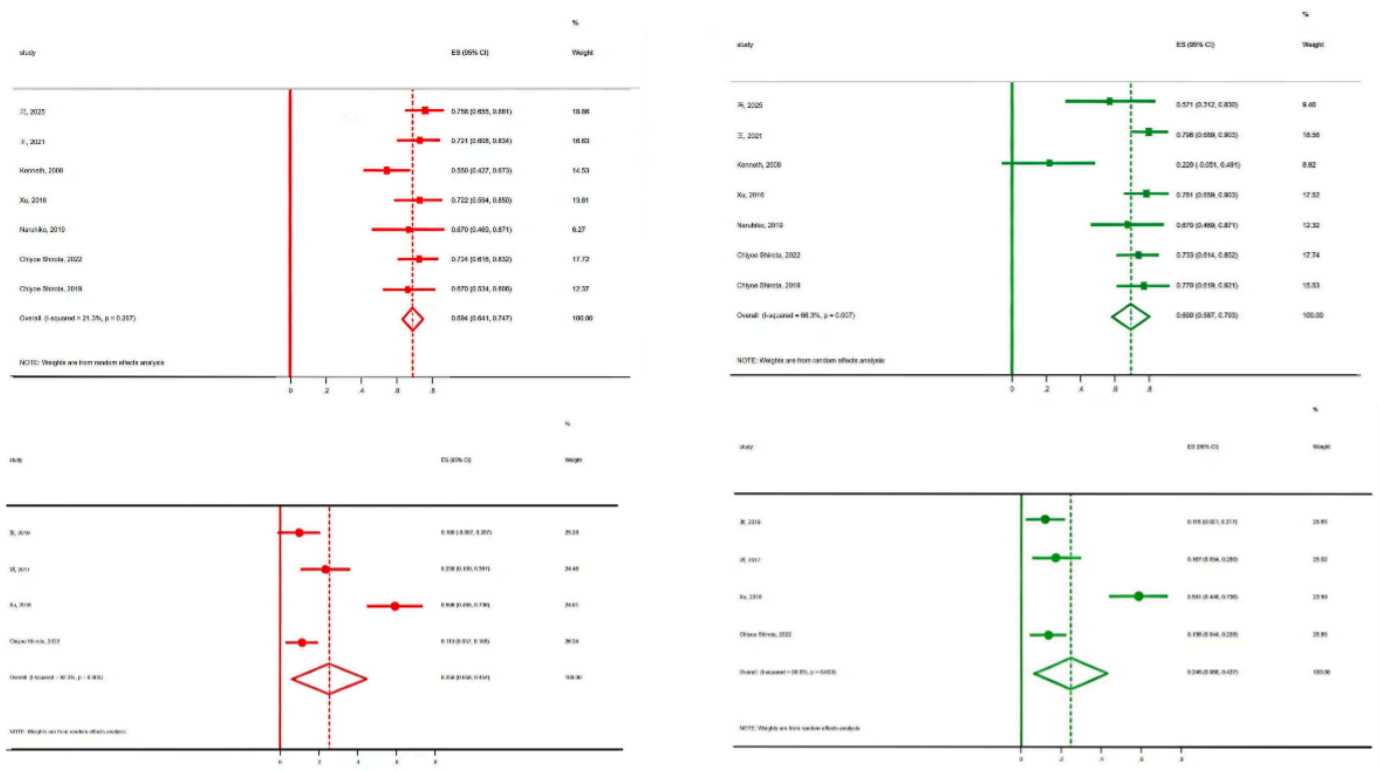


Figure 5. Forest plots for postoperative 1-year native liver survival rate comparing OKP and LKP (A) OKP at 1 year postoperatively (B) LKP at 1 year postoperatively; cholangitis at 3 months postoperatively comparing OKP and LKP (C) OKP at 3 months postoperatively (D) LKP at 3 months postoperatively

Figure 5

See image above for figure legend.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.docx
- SupplementaryTable.docx