SCIENTIFIC PAPER JSLS

T-Tube Use After Laparoscopic Common Bile Duct Exploration

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ABSTRACT

Background and Objectives: Laparoscopic common bile duct exploration (LCBDE) has been verified to be an effective technique in treating choledocholithiasis, and T-tube insertion has been widely performed after LCBDE. With growing doubts regarding the effectiveness and safety of T-tube drainage (TTD), it has been suggested to replace such with primary duct closure (PDC). This meta-analysis aimed to evaluate the short- and long-term effectiveness and safety of PDC compared with TTD after LCBDE.

Methods: The PubMed, Science Citation Index, and Cochrane Central Register of Controlled Trials databases were used to accomplish a systematic literature search for randomized controlled trials and pro-/retrospective cohort studies that compared PDC alone or PDC combined with biliary drainage stenting (PDC+BD) with TTD after LCBDE. A subgroup analysis was established to compare PDC+BD with TTD. RevMan 5.3 was used for the statistical analysis.

Results: A total of 2552 patients from 26 studies were included. The pooled odds ratio supported PDC, which yielded lower postoperative overall morbidity and incidence of bile leak and bile peritonitis and shorter surgical time and postoperative hospital stay when compared with TTD. In the subgroup analysis, PDC+BD showed significantly better results in terms of postoperative overall morbidity, incidence of bile leak and bile peritonitis, surgical time, and postoperative hospital stay than did TTD. PDC and PDC+BD showed no difference in the incidence of recurrent stones and biliary stricture during the long-term follow-up period compared with TTD.

Conclusion: PDC alone or PDC+BD is superior to TTD as a duct-closure method after LCBDE.

Key Words: Laparoscopic common bile duct exploration, Primary duct closure, T-tube drainage, Biliary drainage.

INTRODUCTION

Common bile duct (CBD) stones are a biliary disease requiring surgical intervention. They can form initially in situ, which is mainly attributed to infection and bile stasis, and may also originate secondary to gallbladder stones or intrahepatic bile duct stones[1]; approximately 10%–20% of patients with symptomatic gallstones have CBD stones.[2] Patients presenting with CBD stones are likely to develop biliary colic, obstructive jaundice, cholangitis, or biliary pancreatitis or may stay in the asymptomatic state.

Various techniques for treating CBD stones are feasible and effective. Presently, the popular techniques include laparoscopic cholecystectomy (LC) + laparoscopic common bile duct exploration (LCBDE; single-stage) and LC + pre-/postoperative endoscopic retrograde cholangiopancreatography or that combined with endoscopic sphincterotomy (EST) (two-stage). Both options are effective in detecting and extracting CBD stones[2–4]; however, LC+LCBDE shows advantages in terms of its lower rate of technique failure, fewer number of procedures, shorter hospital stay, and lower hospital charges.[5–7] LCBDE can be performed via either the transductal or transcystic approach, although the latter has less biliary complications; its application is subject to some restrictions; and its success depends on whether the choledochoscope is able to enter the CBD, cystic duct anatomy (diameter, shape, and position of the cystic-CBD junction), and CBD stones (location, size, and number).[8,9]

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Disclosures: None reported.

Conflicts of Interest: All authors declare no conflict of interest regarding the publication of this article.

Informed consent: Dr. Cheng declares that written informed consent was obtained from the patient/s for publication of this study/report and any accompanying images.

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DOI: 10.4293/JSLS.2018.00077

T-tube drainage (TTD) has been widely used for CBD closure when LCBDE was performed via the transductal approach; its functions include biliary tract decompression to prevent further bile leaks, postoperative cholangiography when necessary, and removal of retained stones using a choledochoscope.[10] However, the use of a T tube usually contributes to several postoperative complications with a morbidity of 4%–16.4%[11,12]; the most frequent among such complications is bile leak due to T-tube removal, which is the cause of bile peritonitis, mainly because of an incomplete trans-T-tube sinus-tract formation. The other related problems include CBD obstruction due to T-tube twisting, hydroelectrolytic imbalance as a result of uncontrolled drainage of bile, T-tube-site cellulitis, discomfort and inconvenience to patients with an indwelling T tube, and longer hospital stay due to delayed postoperative recovery.[10,13,14] To avoid these complications associated with T-tube use occurring in LCBDE patients, applying primary duct closure (PDC) alone or PDC combined with internal or external biliary drainage (IBD or EBD, respectively) (antegrade biliary stent, spontaneously removed biliary stent, C-tube, and transcystic biliary decompression) for CBD closure after LCBDE was recommended by some surgeons; further, several clinical trials and meta-analyses have provided supportive views on the use of PDC or PDC combined with other biliary drainage (PDC+BD) techniques, when compared with the use of TTD; the former yielded lower postoperative morbidity and incidence of postoperative biliary peritonitis, shorter surgical time and hospital stay, and lower hospital expenses.[15,16]

However, previous meta-analyses[15–17] that focused on this field contained relatively small sample sizes, and up to only 4 randomized controlled trials were included; it was unreasonable to confuse the bile leak occurring when the T tube was indwelling with that occurring after the T tube was removed; furthermore, retained stones should also not be recognized as a postoperative complication but a cure failure (according to the modified Clavien classification[18]). The above-mentioned deficiencies were common in previous meta-analyses on this topic. In addition, the complications that emerged during follow-up periods, such as biliary stricture and recurrent stones, were not analyzed in detail. Thus, we conducted this meta-analysis based on a larger cohort of 2552 patients to evaluate the potential advantages or limitations of PDC alone or PDC+BD compared with TTD in a more reasonable and comprehensive approach.

METHODS

Data Sources and Search Strategies

A literature search was conducted using the PubMed (October 1976 to May 2018), Cochrane Central Register of Controlled Trials (1983–2017), and Science Citation Index (October 1976 to May 2018) databases to select studies comparing PDC/PDC+BD with TTD. We utilized the following search terms for retrieval: T tube, PDC, or primary closure or primary suture, LCBDE, and choledocholithiasis. Further, similar articles recommended by the databases were taken into account, and relevant articles from the reference lists were retrieved by manual search.

Study Selection

Clinical trials (randomized controlled trials, retrospective cohort studies, and prospective cohort studies) were included in this meta-analysis for the purpose of comparing PDC/PDC+BD with TTD after LCBDE. If more than one publication reported the results of a single study, the most recent article and that with more complete data were selected for the meta-analysis. There was no restriction in the language of the articles.

Irrelevant studies, noncontrol studies, review articles, nonhuman studies, unpublished materials and abstracts, letters, and case reports were excluded.

The inclusion criteria for the studies were as follows:

1. Patients diagnosed with choledocholithiasis or CBD stones
2. Illustrated demographic and clinical features of the patients
3. Patients without absolute contraindication for laparoscopic surgery
4. Patients without severe acute cholangitis, ampullary stenosis with multiple intrahepatic stones, suspected biliary neoplasia, liver cirrhosis, or hemorrhagic tendency
5. Reported at least one of the following outcomes: 1) postoperative overall morbidity; 2) biliary-specific complications (bile leak, bile peritonitis, and CBD obstruction); 3) surgical time; 4) length of postoperative hospital stay; 5) recurrent stones; and 6) postoperative biliary stricture

Preliminary screening and full-article assessment were performed independently by two reviewers (JC and ZX).

Disagreements were resolved through mutual discussion or evaluated by a third reviewer (CS).

Data Extraction and Study Quality Assessment

Two review authors (JC and ZX) independently extracted the data from the included studies and checked the extracted data together. Disagreements on the extracted data were resolved by consulting relevant knowledge. The clinical outcomes extracted included as follows: 1) characteristics of the studies (study type, number of patients assigned to each technique group, T-tube type, T-tube removal time, and follow-up period); 2) number of patients who experienced postoperative overall complications, bile leak, bile peritonitis, CBD obstruction, postoperative pancreatitis, recurrent stones, biliary stricture, and other complications; and 3) surgical time and length of postoperative hospital stay.

We used the Cochrane Collaboration Risk of Bias Tool[19] to assess the risk of bias for the randomized controlled trials; the quality of the retrospective cohort studies and prospective cohort studies was assessed in accordance with the recommendations suggested by the Newcastle-Ottawa quality assessment tool.[20]

Statistical Analysis

The software RevMan 5.3 was applied for the statistical analysis. The heterogeneity among the studies was examined using χ^2 test. When the I^2 value was ≤50%, the heterogeneity could be accepted. If the P value of the heterogeneity test was greater than .10, it was considered that homogeneity existed among the studies. The fixed-effect model (Mantel-Haenszel method) was used to calculate the summary statistics; when substantial heterogeneity ($P \leq .01$; $I^2 > 50\%$) was detected, the random-effect model (DerSimonian and Laird method) was used for the analysis.

Dichotomous variables were analyzed using odds ratios (ORs) with 95% confidence intervals (CIs) and continuous variables using weighted mean differences with 95% CIs. Peto ORs were applied for very low incidence outcome analyses to minimize bias. If $P \leq .05$, and the 95% CI did not contain the value 1, the OR/Peto OR was considered to indicate a significant difference; if the $P \leq .05$, and the 95% CI did not contain the value 0, the weighted mean differences was considered to indicate a significant difference.

RESULTS

Study Search and Description

A total of 369 articles were identified through the electronic database search (368 articles) and manual search (one article); the manually retrieved study[21] was identified from the reference list of one of the other relevant articles.[22] After reviewing the titles and abstracts of these obtained articles, 339 were excluded because they were irrelevant studies, noncontrol studies, systematic reviews, animal studies, or studies that focused on open common bile duct exploration (CBDE). The full texts of the 30 remaining studies were then assessed. Finally, 26 studies[9,12,21,23–45] were eligible for this meta-analysis. Seven were randomized controlled trials,[9,21,23,24,38,42,43] and the other 19 were retrospective cohort studies or prospective cohort studies. Sixteen studies[9,12,21,23,26,28,30,33,34,37–41,43,44] compared LCBDE+PDC with LCBDE+TTD. Eight studies[24,25,28,29,32,36,42,45] compared LCBDE+PDC+IBD with LCBDE+TTD; three studies[27,31,35] compared LCBDE+PDC+EBD with LCBDE+TTD; and one study[28] compared three bile duct closure methods following LCBDE (**Table 1**). The descriptions of the various IBD and EBD technical processes are listed in **Table 2**. A total of 2552 patients were included in this meta-analysis.

Quality Assessment

The quality of the seven randomized controlled trials was assessed using the Cochrane Collaboration Risk of Bias Tool; the final judgment of all the randomized controlled trials was "unclear risk of bias." The quality of the 15 retrospective cohort studies and 4 prospective cohort studies was assessed using the Newcastle-Ottawa quality assessment tool; all the retrospective cohort studies and prospective cohort studies could be awarded 4–7 stars.

Postoperative Overall Morbidity

In the 16 studies[9,12,21,23,26,28,30,33,34,37–41,43,44] that compared LCBDE+PDC with LCBDE+TTD, 74 patients (7.5%) in the PDC group and 106 patients (12.8%) in the TTD group developed postoperative complications; the PDC group showed a significantly lower overall morbidity than did the TTD group (OR = 0.55, 95% CI = 0.39–0.76, $P = .0004$; no heterogeneity was found; $I^2 = 0\%$; $P = .91$) (**Figure 1A**). Thirty-three of the 106 patients developed postoperative complications due to T-tube removal or accidental dislodgement in the TTD group[9,12,21,23,26,28,30,33,34,38,39,43] (**Table 2**).

Table 1.
Characteristics of the 26 Included Studies

Study	Number of Patient		Intervention		T-tube Type and Removal Time	Follow-up
	Study Group	Control Group	Study Group	Control Group		
Martin et al[12] (RCS)	55	61	PDC	TTD	NA; Clamped at 7d,removed at 21d	Unclear
Cai et al[39] (RCS)	134	100	PDC	TTD	NA; 12w after operation	median 26m
Dong et al[38] (RCT)	97	90	PDC	TTD	14–20Fr latex rubber T-tube; 3–4w after operation	median 12m
El-Geidie et al[9] (RCT)	61	61	PDC	TTD	14–16Fr latex rubber T-tube; 10d after operation	at 2w and 2m
Ha et al[41] (PCS)	12	26	PDC	TTD	NA; 14d after operation	every 3m
Parra-Membrives et al[28] (RCS)	36	52	PDC	TTD	10–16Fr rubber T-tube; 1m after operation	1m and 6m after operation
Shakya et al[21] (RCT)	20	20	PDC	TTD	12/14Fr; 11d after operation	Unclear
Wang et[30] (PCS)	132	108	PDC	TTD	6 and 8 mm in diameter; 12w after operation	12w after discharge or T-tube removal
Jameel et al[44] (PCS)	48	10	PDC	TTD	NA; 3–4w after discharge	6w after discharge
Liu et al[34] (RCS)	49	12	PDC	TTD	NA; unclear	1y after operation
Wen et al[26] (RCS)	52	33	PDC	TTD	16–20Fr latex rubber T-tube; 4w after operation	Unclear
Yi et al[37] (RCS)	91	51	PDC	TTD	16Fr; 2w after operation	median 48.8m
Zhang HW et al[33] (RCS)	93	92	PDC	TTD	NA; 14d after operation	median 40m
Zhang K et al[40] (RCS)	25	25	PDC	TTD	NA; 4–6w after operation	6w after operation, median 18m
Zhang LD et al[23] (RCT)	40	40	PDC	TTD	14–20Fr latex rubber T-tube; 3–4w after operation	25m average
Zhang WJ et al[43] (RCT)	47	46	PDC	TTD	14–20Fr latex rubber T-tube; 3–5w after operation	3–24m after discharge
Griniatsos et al[29] (RCS)	21	32	PDC+IBD	TTD	NA; 16d after operation (14–17d)	unclear
Kim and Lee et al[36] (RCS)	50	36	PDC+IBD	TTD	NA; 32 ±7.5d after operation	unclear
Lyon et al[45] (PCS)	82	34	PDC+IBD	TTD	NA; 4–5w after operation	unclear
Mangla et al[24] (RCT)	31	29	PDC+IBD	TTD	NA; 11d after operation	unclear

Table 1.
Continued

Study	Number of Patient		Intervention		T-tube Type and Removal Time	Follow-up
	Study Group	Control Group	Study Group	Control Group		
Martinez-Beana et al[32] (RCS)	28	47	PDC+IBD	TTD	8–14Fr latex Kehr tube; 1m after operation	unclear
Tang et al[25] (RCS)	35	28	PDC+IBD	TTD	16Fr, 2w after operation	every 3m after discharge
Xu et al[42] (RCT)	22	25	PDC+IBD	TTD	NA, 14–21d after operation	unclear
Parra-Membrives et al[28] (RCS)	58	52	PDC+IBD	TTD	10–16Fr rubber T-tube; 1m after operation	1m and 6m after operation
Huang et al[35] (RCS)	10	40	PDC+EBD	TTD	16–20Fr rubber T-tube; 8d after operation	median 35.4m
Kanamaru et al[31] (RCS)	30	15	PDC+EBD	TTD	NA; 3–4w after operation	unclear
Wei et al[27] (RCS)	30	52	PDC+EBD	TTD	12–16Fr latex rubber T-tube; 3–4w after operation	3–40w

d: days; w: weeks; m: months; PDC: primary duct closure; TTD: T-tube drainage; IBD: internal biliary drainage; EBD: external biliary drainage; RCT: randomized controlled trial; RCS: retrospective cohort study; PCS: prospective cohort study; NA: not available.

In the 11 studies[24,25,27–29,31,32,35,36,42,45] included in the subgroup analysis, 45 patients (11.3%) in the LCBDE+PDC+BD group and 71 patients (18.2%) in the LCBDE+TTD group developed postoperative complications; the PDC+BD group showed a significantly lower overall morbidity than did the TTD group (OR = 0.58, 95% CI = 0.38–0.89, P = .01; the heterogeneity could be accepted; I^2 = 31%; P = .15) (**Figure 1B**). Twenty-six patients[27–29,32,36,45] in the TTD group developed complications associated with T tube use (**Table 2**).

Bile Leak

In 16 studies,[9,12,21,23,26,28,30,33,34,37–41,43,44] 46 patients (4.6%) in the PDC group and 59 patients (7.1%) in the TTD group had bile leak. The result tended to favor the PDC group, which showed a lower incidence of bile leak; however, no significant difference was found (OR = 0.68, 95% CI = 0.45–1.03, P = .07; no heterogeneity was found; I^2 = 0%; P = .99) (**Figure 2A**). Twenty patients[21,23,26,28,30,33,34,38,39,43] in the TTD group experienced bile leak as a result of planned T-tube removal, removal by mistake, or accidental dislodgement. When we excluded the 20 bile-leak cases and compared the patients with bile leak occurring when the T tube was in situ with the PDC group patients, no difference in the incidence of bile leak was found (OR = 1.04, 95% CI = 0.67–1.61, P = .86; no heterogeneity was found; I^2 = 0%, P = .97) (**Figure 2C**).

In the 11 studies[24,25,27–29,31,32,35,36,42,45] included in the subgroup analysis, 23 patients (5.8%) in the PDC+BD group and 40 patients (10.3%) in the TTD group had bile leak. The PDC+BD group showed a significantly lower incidence of bile leak than did the TTD group (OR = 0.57, 95% CI = 0.33–0.96, P = .04; no heterogeneity was found; I^2 = 0%, P = .49) (**Figure 2B**). Eighteen patients[27–29,32,36,45] in the TTD group had bile leak as a result of planned T-tube removal or accidental dislodgement; when these patients were excluded and compared, the result showed no difference between them (OR = 1.09, 95% CI = 0.60–1.98, P = .77; no heterogeneity was found; I^2 = 0%, P = .73) (**Figure 2D**).

Bile Peritonitis

Seventeen patients[9,12,23,26,28,30,38,39,43] in the TTD group and none in the PDC group had bile peritonitis; the result showed a significant difference (OR = 0.2, 95% CI = 0.07–0.55, P = .002; no heterogeneity was found; I^2 = 0%, P = 1.00) (**Figure 3A**). Of these 17 patients,[23,26,28,30,38,39,43] nine patients had bile peritonitis due to T-tube removal

Table 2.
Complications Associated with TTD

PDC vs TTD	T-tube accidental dislodgement	8	A total of eight patients had T-tube accidental dislodgement, two of whom developed bile leak and bile peritonitis. Three patients were treated with reoperation for T-tube replacement, while the treatment in the other five patients was not mentioned.
	Complications due to T-tube removal	23	There were 18 patients who had bile leak after T-tube removal, 10 of whom developed bile peritonitis; the five remaining patients developed other complications following T-tube removal.
	T-tube twisting	2	Two patients developed CBD obstruction due to T-tube twisting.
	Total	33	
PDC+BD vs TTD	T-tube accidental dislodgement	4	Four patients had T-tube accidental dislodgement, one of whom experienced bile leak and bile peritonitis. One patient received reoperation for T-tube replacement.
	Complications due to T-tube removal	22	Seventeen patients experienced bile leak after T-tube removal, 11 of whom developed bile peritonitis; the five remaining patients developed other complications following T-tube removal.
	T-tube twisting	0	
	Total	26	

PDC: primary duct closure; TTD: T-tube drainage; BD: biliary drainage; CBD: common bile duct.

and three patients, T-tube accidental dislodgement. We excluded 12 patients and compared the findings, and the Peto OR was applied owing to the low incidence; the result favored the PDC group, which also showed a significant difference (OR = 0.14, 95% CI = 0.02–0.82, P = .03; no heterogeneity was found; I^2 = 0%, P = .96) (**Figure 3C**).

In the seven studies[27–29,32,35,36,45] included in the subgroup analysis, one patient in the PDC+BD group and 14 patients in the TTD group experienced bile peritonitis; the result favored the PDC+BD group, which showed a significant difference (OR = 0.26, 95% CI = 0.09–0.77, P = .01; no heterogeneity was found; I^2 = 0%, P = .82) (**Figure 3B**). Twelve patients[27–29,32,36,45] in the TTD group developed bile peritonitis due to T-tube removal or T-tube accidental dislodgement; we then excluded these patients and analyzed the findings, and the Peto OR was applied owing to the low incidence. The result tended to favor the PDC+BD group but showed no significant difference (Peto OR = 0.23, 95% CI = 0.01–5.30, P = .36; no heterogeneity was found; I^2 = 0%, P = .92) (**Figure 3D**).

CBD Obstruction

Two patients in the PDC group (one had a stitch occluding the bile duct, and one had ampullary edema) and 2 patients (T-tube twisting) in the TTD group had CBD obstruction after surgery; the result had no significant difference between the two groups[12,23,43] (Peto OR = 1.05, 95% CI = 0.15–7.48, P = .96; the heterogeneity could be accepted; I^2 = 53%, P = .12) (**Figure 4A**).

Tang et al[25] reported CBD obstruction cases due to stent blockage in the PDC+BD group, but provided no detailed data, no CBD obstruction was noted in the TTD group.

Postoperative Pancreatitis

In 3 studies,[23,38,43] 3 patients in the PDC group and one patient in the TTD group had postoperative pancreatitis; the result tended to favor the TTD group. However, no significant difference was discovered (Peto OR = 2.67,

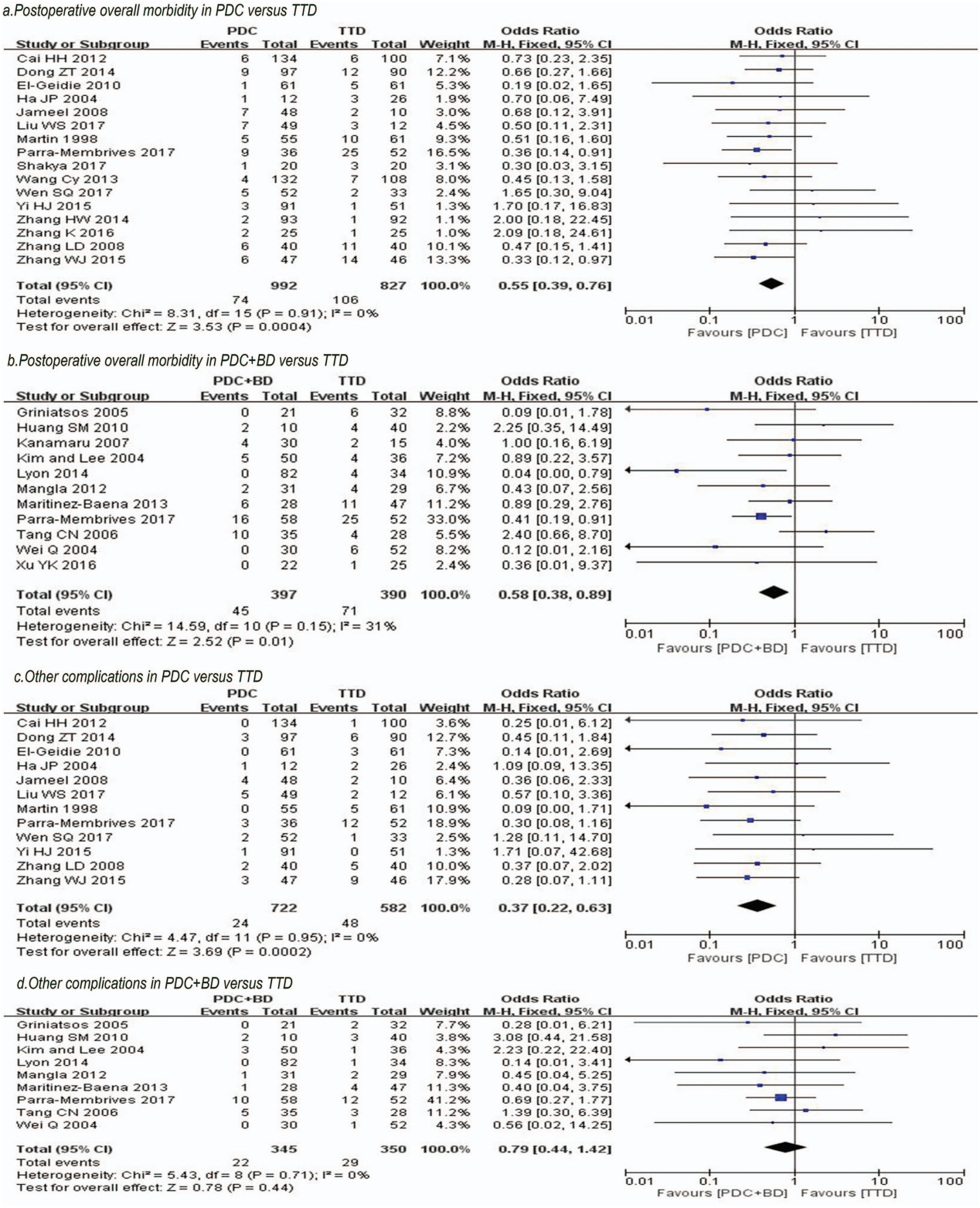

Figure 1. Forest plots of postoperative overall morbidity and other complications. PDC, primary duct closure; TTD, T tube drainage; BD, biliary drainage; CI:, confidence interval.

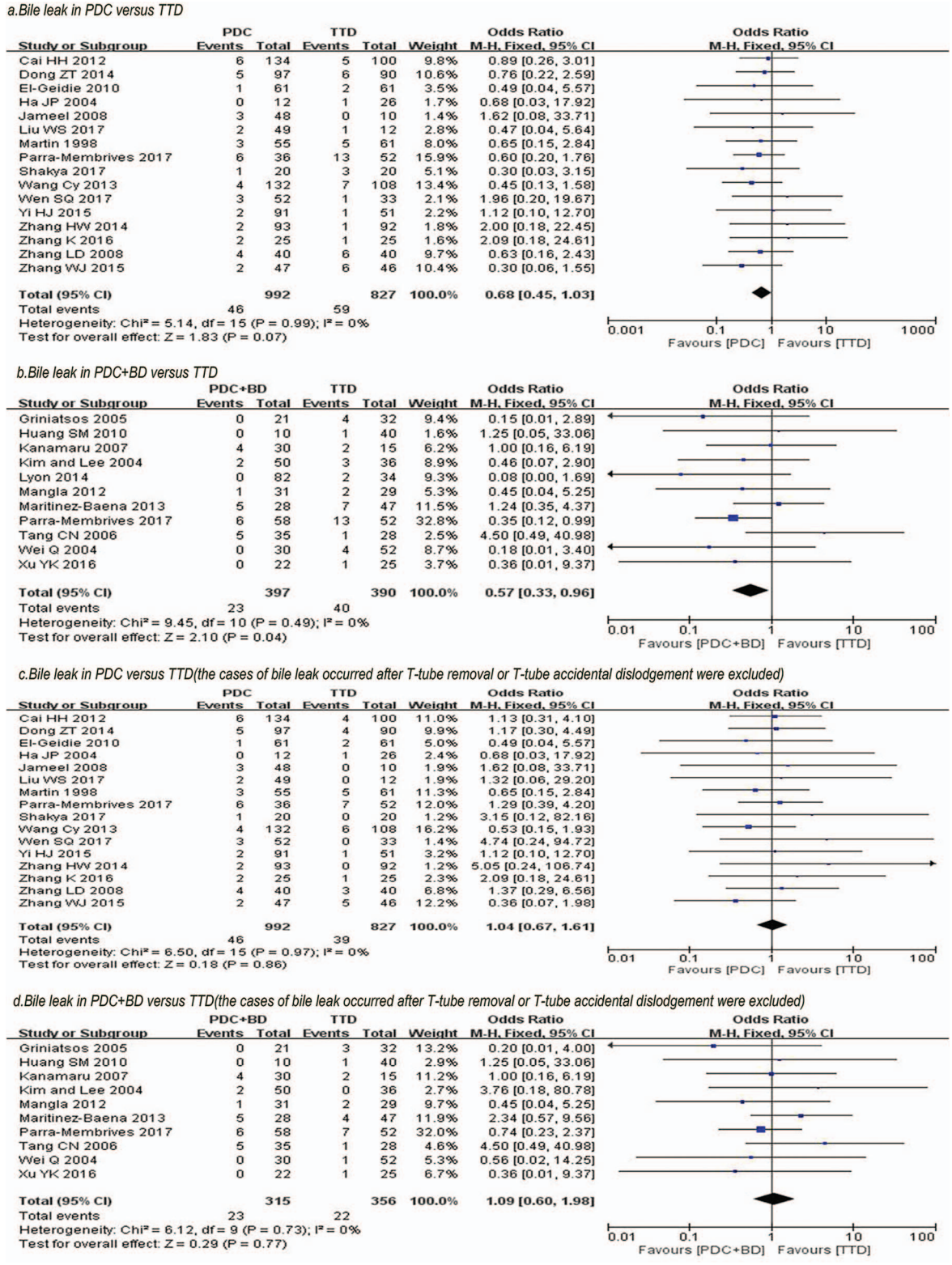

Figure 2. Forest plots of bile leak. PDC, primary duct closure; TTD, T tube drainage; BD, biliary drainage; CBD, common bile duct; CI, confidence interval.

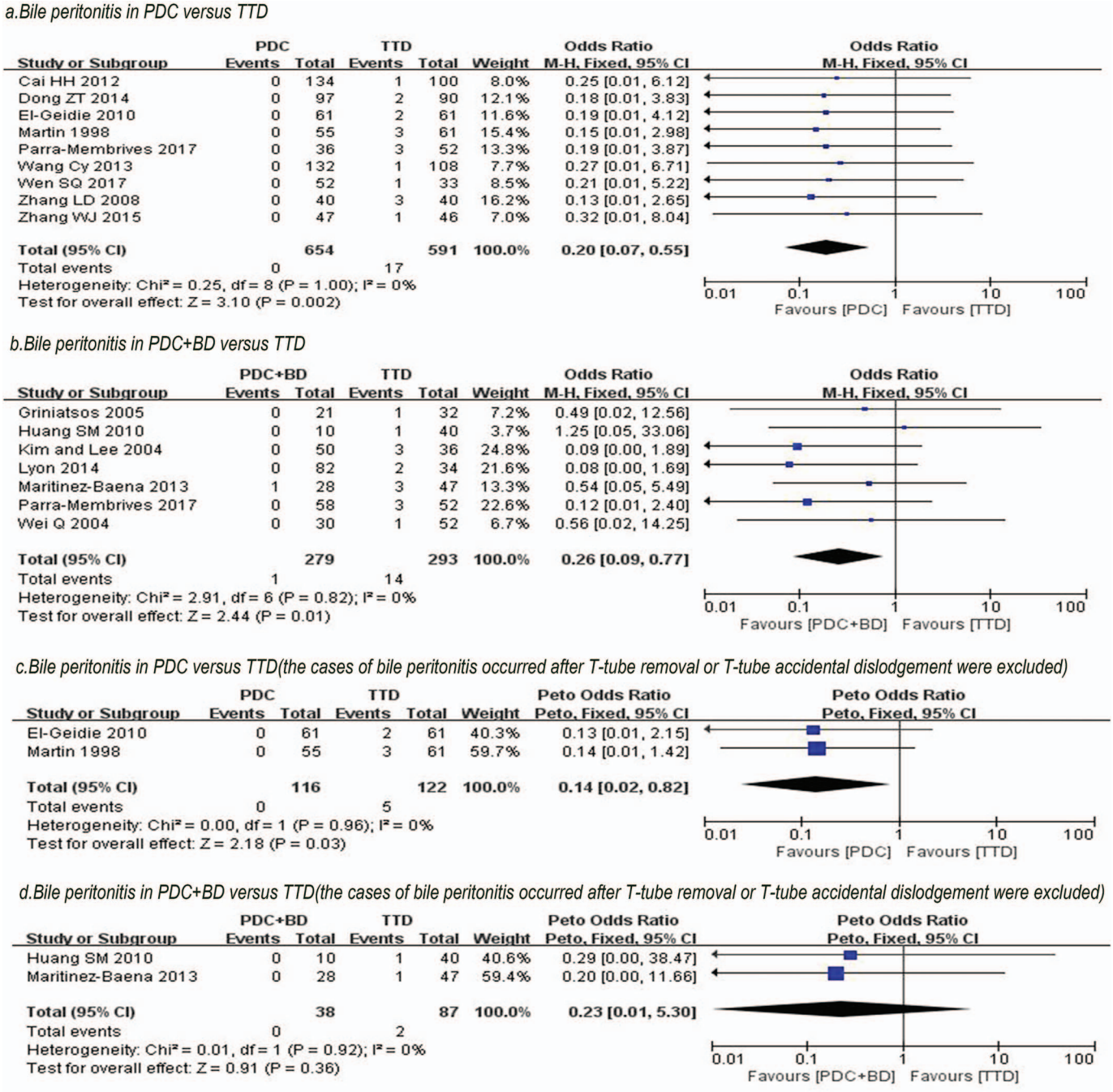

Figure 3. Forest plots of bile peritonitis. PDC, primary duct closure; TTD, T tube drainage; BD, biliary drainage; CI, confidence interval.

95% CI = 0.37–19.09, P = .33; no heterogeneity was found; I^2 = 0%, P = .62) (**Figure 4B**).

One patient[32] in the TTD group had postoperative pancreatitis due to T-tube migration; none of the patients in the PDC+BD group developed postoperative pancreatitis.

Other Complications

The other complications included stent migration or blockage, T-tube dislodgement or twisting, other nonbiliary complications due to T-tube removal, wound infection, pneumonia, intra-abdominal bleeding, and venous thrombus.

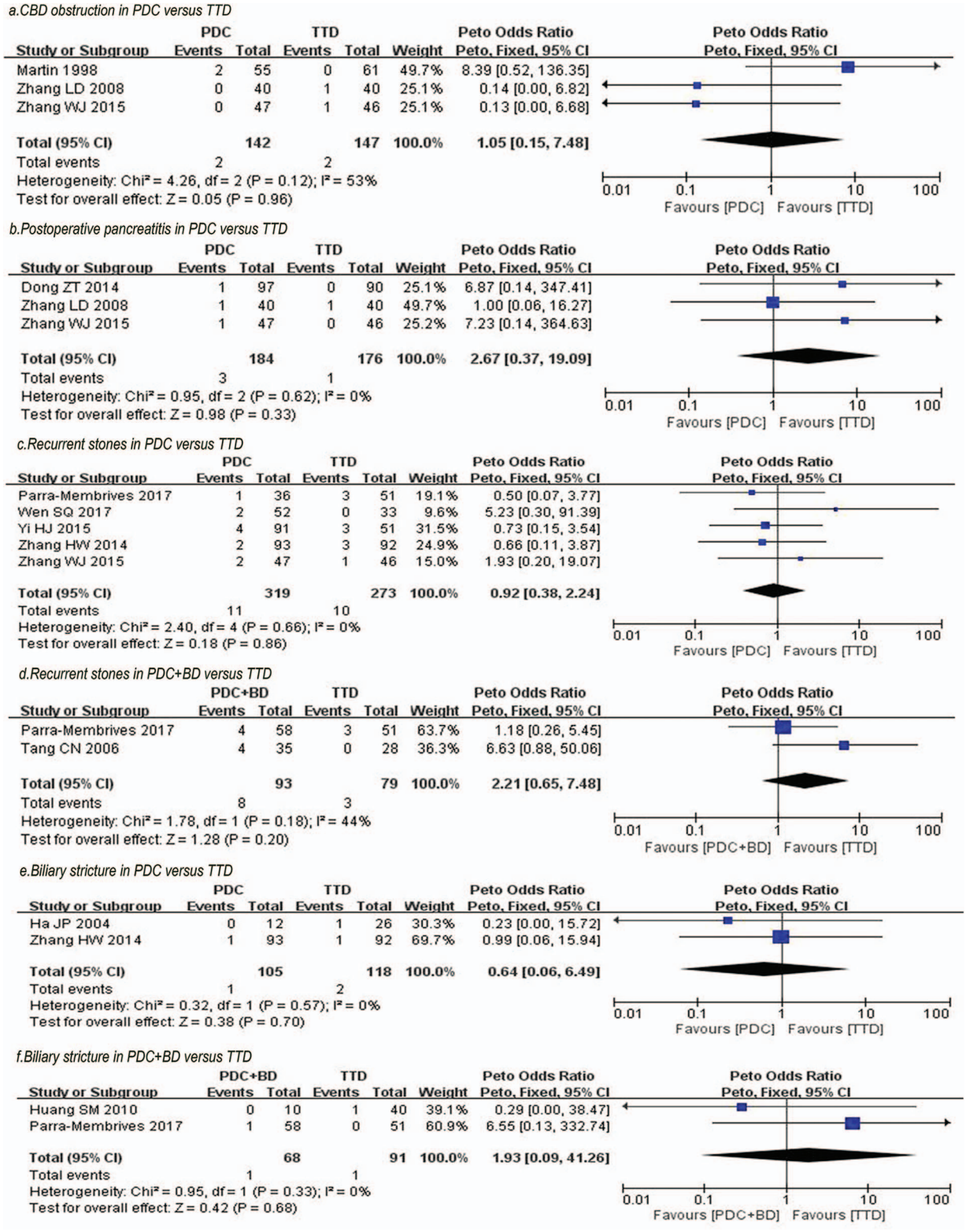

Figure 4. Forest plots of CBD obstruction, postoperative pancreatitis, recurrent stones, and biliary stricture. PDC, primary duct closure; TTD, T tube drainage; BD, biliary drainage; CBD, common bile duct; CI, confidence interval.

Twenty-four patients in the PDC group and 48 patients in the TTD group developed other postoperative complications; the PDC group had a significantly lower incidence of other complications[9,12,23,26,28,34,37–39,41,43,44] (OR = 0.37, 95% CI = 0.22–0.63, P = .0002; no heterogeneity was found; I^2 = 0%, P = .95) (**Figure 1C**). Fifteen patients[9,12,21,23,26,28,30,33,34,38,39,43] in the TTD group had T-tube dislodgement, T-tube twisting, or nonbiliary complications after T-tube removal (**Table 2**).

In the subgroup analysis, 22 patients in the PDC+BD group and 29 patients in the TTD group had other postoperative complications; the result tended to favor the PDC+BD group but showed no significant difference[24,25,27–29,32,35,36,45] (OR = 0.79, 95% CI = 0.44–1.42, P = .44; no heterogeneity was found; I^2 = 0%, P = .71) (**Figure 1D**). Seven patients in the PDC+BD group had stent migration and dislodgement.[27,28] Nine patients in the TTD group had T-tube dislodgement or nonbiliary complications after T-tube removal[27–29,32,45] (**Table 2**).

Recurrent CBD Stones

Recurrence of CBD stones was defined as development of stones not earlier than 6 months after the initial CBD stones were completely removed.[46,47]

Eleven studies[23,26,28,30,33,37–40,41,43] that compared PDC with TTD investigated recurrent CBD stones during the follow-up period; in 5 studies,[26,28,33,37,43] 11/759 (1.4%) patients in the PDC group and 10/662 (1.5%) patients in the TTD group had recurrent CBD stones during the follow-up period. However, no significant difference was discovered (Peto OR = 0.92, 95% CI = 0.38–2.24, P = .86; no heterogeneity was found; I^2 = 0%, P = .66) (**Figure 4C**).

In the subgroup analysis, 4 studies[25,27,28,35] investigated recurrent CBD stones, and two studies[25,28] reported positive findings. Further, 8/147 (5.4%) patients in the PDC+BD group and 3/155 (1.9%) patients in the TTD group had recurrent CBD stones during the follow-up period. However, the result had no significant difference (Peto OR = 2.21, 95% CI = 0.65–7.48, P = .20; the heterogeneity could be accepted; I^2 = 44%, P = .18) (**Figure 4D**).

Biliary Stricture

Eleven studies[23,26,28,30,33,37–40,41,43] that compared PDC with TTD reported biliary stricture during the follow-up period; in two studies,[33,41] one patient in the PDC group and two patients in the TTD group had biliary stricture during the follow-up period. However, the result had no significant difference (Peto OR = 0.64, 95% CI = 0.06–6.49, P = .70; no heterogeneity was found; I^2 = 0%, P = .57) (**Figure 4E**).

In the subgroup analysis, one patient in the PDC+BD group and one patient in the TTD group had biliary stricture during the follow-up period[28,35]; however, the result had no significant difference (Peto OR = 1.93, 95% CI = 0.09–41.26, P = .68; no heterogeneity was found; I^2 = 0%, P = .33) (**Figure 4F**).

Surgical Time

Thirteen studies[9,21,23,26,30,33,34,37–41,43] compared the surgical time; the surgical time was significantly shorter in the PDC group than in the TTD group (weighted mean differences, −20.65, 95% CI = −30.17 to −11.13, P < .0001; a heterogeneity was found; I^2 = 96%, P < .00001) (**Figure 5A**).

In the subgroup analysis, seven studies[24,25,27,29,31,35,36] reported the surgical time; the surgical time was significantly shorter in the PDC+BD group than in the TTD group (weighted mean differences, −18.61, 95% CI = −32.10 to 5.12, P = .007; a heterogeneity was found; I^2 = 84%, P < .00001) (**Figure 5B**).

Postoperative Hospital Stay

Twelve studies[9,23,26,30,33,34,37–40,41,43] reported the duration of postoperative hospital stay; the PDC group had a significantly shorter hospital stay duration (weighted mean differences. −2.89, 95% CI =−3.96 to 1.82, P < .00001; a heterogeneity was found; I^2 = 96%, P < .00001) (**Figure 5C**).

In the subgroup analysis, the PDC+BD group had a significantly shorter hospital stay duration[24,25,27,29,31,32,35,36,45] (weighted mean differences, −3.16, 95% CI = −4.65 to 1.68, P < .0001; a heterogeneity was found; I^2 = 94%, P < .00001) (**Figure 5D**).

Publication Bias

No significant publication biases were found on the basis of the funnel plots of the postoperative overall morbidity and bile leak (**Figure 6**).

DISCUSSION

The traditional management after LCBDE for choledocholithiasis is insertion of a T tube; this biliary decompression measure is necessary in cases when high pressure

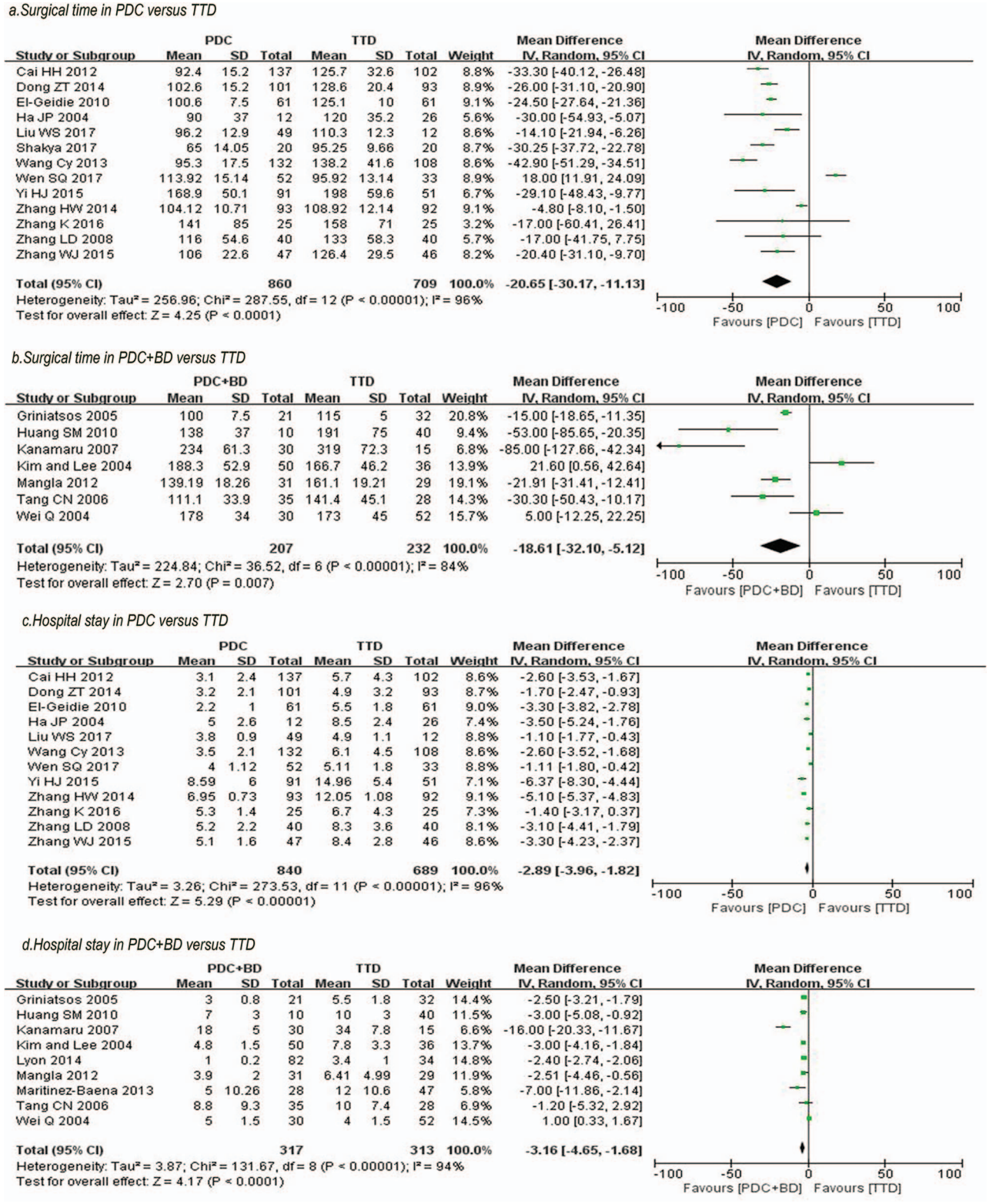

Figure 5. Forest plots of surgical time and hospital stay. PDC, primary duct closure; TTD, T tube drainage; BD, biliary drainage; CI, confidence interval.

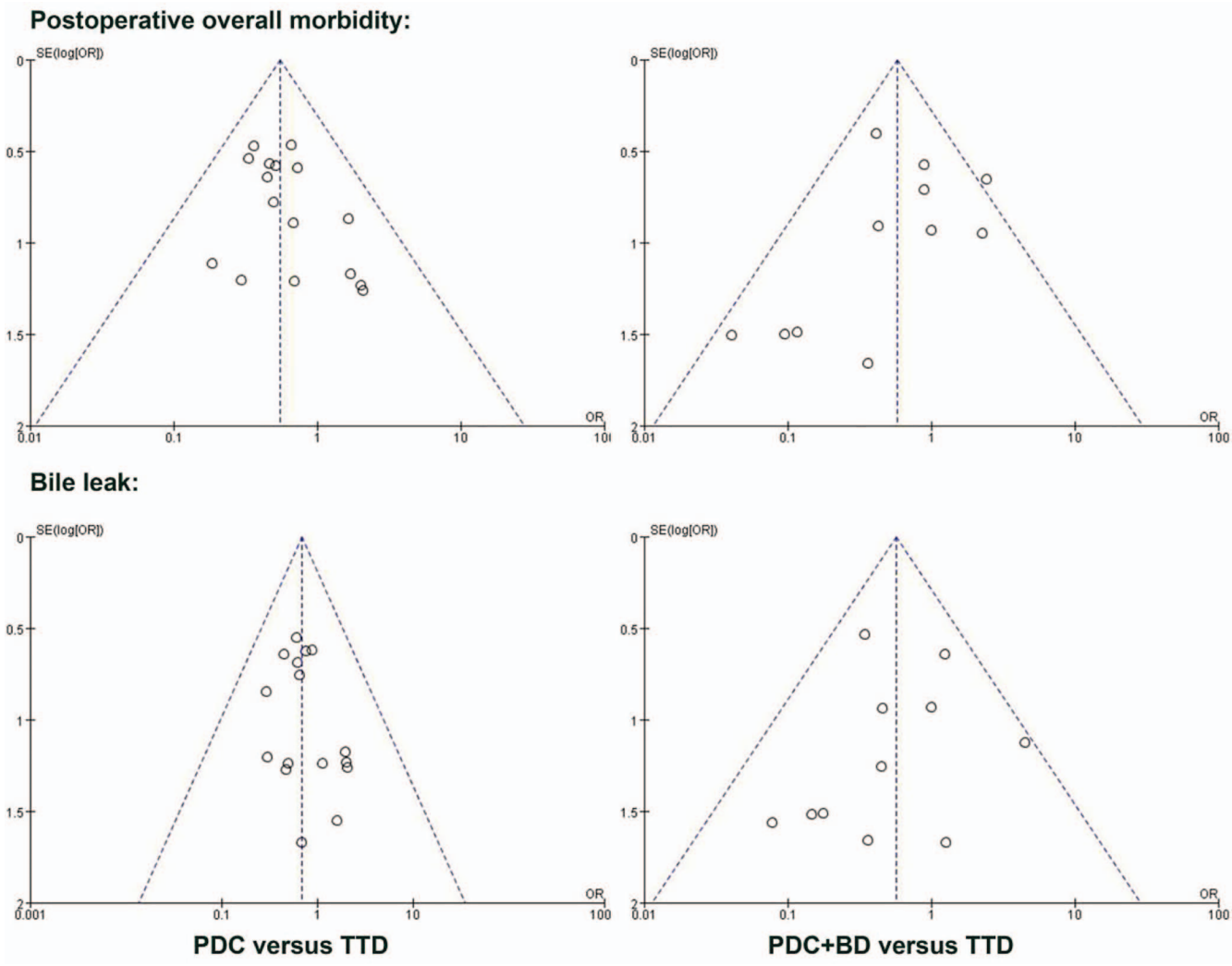

Figure 6. Funnel plots of the distribution of the ORs for postoperative overall morbidity and bile leak of 16 studies comparing PDC with TTD and 11 studies comparing PDC+BD with TTD. PDC, primary duct closure; TTD, T tube drainage; BD, biliary drainage; OR, odds ratio.

exists in biliary tract, with the role of preventing postoperative biliary stricture and treating residual stones conveniently. However, TTD is associated with a number of postoperative complications and causes inconvenience to patients in terms of management of the T tube for a long period after discharge.

Our analysis showed a significantly decreased postoperative overall morbidity in the PDC/PDC+BD group compared with that in the TTD group. More than 30% of the postoperative complications that occurred in the TTD group were associated with T-tube removal, accidental dislodgement, or T-tube twisting. Wills et al[13] demonstrated that significant morbidity was associated with T-tube insertion after choledochotomy; more than half of the complications were due to planned T-tube removal or dislodgement. Yin et al[15] reported a higher incidence of overall and biliary-specific complications when the T tube was removed between 8 and 16 days than when the T tube was removed after more than 21 days. Therefore, T-tube removal or accidental dislodgement can be recognized as an important cause of the significant increase in postoperative morbidity in TTD compared with that in PDC or PDC+BD.

The incidence of bile leak was lower in the PDC group than in the TTD group (OR = 0.68, P = .07) and in the PDC+BD group than in the TTD group (OR = 0.57, P =

.04). However, some patients in the TTD group had bile leak due to planned T-tube removal or accidental dislodgement. This is probably because of the premature removal of the T tube. Laparoscopic surgery reduces abdominal inflammatory response and adhesion formation compared with open surgery. The material of the T tube has been changed from the previous red rubber to the current silicon-coated latex; the latter is less irritating to abdominal inflammation. Both conditions lead to slow formation of the trans-tube sinus tract composed of granulation and fibrous tissues. In this case, bile leak may occur and develop into bile peritonitis after T-tube removal, since bile flows out of the immature trans-tube sinus tract.[14,48] He et al[16] compared the ORs of bile leak between short- (less than 3 weeks) and long-term (more than 3 weeks) T-tube indwelling; however, no meaningful results were found (less than 3 weeks: OR = 0.79, $P = .74$ in PDC versus TTD; OR = 1.20, $P = .73$ in PDC+BD versus TTD; more than 3 weeks: OR = 1.27, $P = .54$ in PDC versus TTD; OR = 0.82, $P = .64$ in PDC+BD versus TTD); hence, the suitable time of T-tube removal needs further exploration. Wills et al[13] presented that T-tube indwelling has a minimal effect of preventing the occurrence of bile leak, with cases of biliary peritonitis occurring after the T tube had been indwelling for 1 month. Similarly, when we excluded the cases of bile leak due to inappropriate T-tube removal, the pooled ORs of bile leak between the PDC and TTD groups and between the PDC+BD and TTD groups were 1.04 and 1.09, respectively. The results indicated that although decompression TTD was performed, the incidence of bile leak did not decrease. In other words, TTD seemed to have equal effects as PDC alone or PDC+BD in managing bile leak when T tube is continuously indwelling without the circumstance of inappropriate T tube removal or dislodgement. However, the use of PDC is limited by swelling of the sphincter of Oddi and severe acute pyogenic cholangitis because both conditions can cause increased pressure in the biliary tree; further, CBD drainage for decompression of the biliary system is required.[33] Therefore, PDC may be necessary to be combined with BD methods for the purpose of CBD decompression in such cases.[42,45]

The incidence of bile peritonitis was significantly higher in the TTD group than in the PDC group; further, 12/17 patients in the TTD group had bile peritonitis due to T-tube removal or dislodgement. In the subgroup analysis, a significantly higher incidence of bile peritonitis in the TTD group than in the PDC+BD group was found, and 12/14 patients had bile peritonitis due to T-tube removal or dislodgement. This is probably due to the immature T-tube sinus tract or disruption of the sinus tract during the T-tube removal process.[48] Further, the bile directly flows into the peritoneal cavity without being timely controlled; consequently, bile peritonitis or local biloma emerges.

The incidence of other complications increased significantly in the TTD group compared with that in the PDC group probably because the complications associated with T-tube use accounted for a considerable proportion in the TTD group; the views on postoperative complications identified may vary among different physicians, and some mild and temporary postoperative problems without the need for interventions are considered as complications. No significant difference was found in other complications between PDC+BD and TTD.

The incidence of recurrent stones showed no significant difference between PDC and TTD and between PDC+BD and TTD; a relatively low incidence of recurrent stones was found. Further, 11/759 (1.4%) patients in the PDC group and 10/662 (1.5%) patients in the TTD group had recurrent CBD stones. In the subgroup analysis, 8/147 (5.4%) patients in the PDC+BD group and 3/155 (1.9%) patients in the TTD group had recurrent CBD stones. The risk factors for recurrent stones mainly included bile stasis, sustained dilation of the bile duct, aberrant papilla location, and duodenal-biliary reflux[46,47]; based on these and our findings, various types of treatment modalities after LCBDE may not be associated with recurrent CBD stones, and more well-designed clinical trials are needed to confirm this.

Biliary stricture seems rare after choledochotomy in LCBDE; the risk factor of biliary stricture after LCBDE is mainly related to a short CBD diameter. The appropriate CBD diameter for a safe and successful choledochotomy remains controversial for the purpose of preventing biliary stricture after choledochotomy; in imaging studies, a CBD diameter larger than 8 mm was recommended for LCBDE.[37] Gigot et al[49] suggested a CBD diameter larger than 9 mm if PDC is implemented following choledochotomy. Our findings revealed no difference in the incidence of biliary stricture between PDC/PDC+BD and TTD, and very few patients had biliary stricture during the follow-up period. Decker et al[50] investigated 100 patients who underwent laparoscopic choledochotomy and found that none of them had biliary stricture after PDC. Therefore, PDC/PDC+BD and TTD may have a minimal contribution on biliary stricture if PDC is performed under a suitable CBD diameter.

The TTD group had a longer surgical time and hospital stay probably because of the complex procedures in T-tube insertion and subsequent CBD incision closure during surgery; further, TTD patients need a longer time for postoperative recovery and ensuring the patency of the T tube. However, under the diverse medical policies in different hospitals for hospital stay, eg, pursuing shorter lengths of hospital stay, the impact of man-made interference might generate bias in the results.

We conducted this meta-analysis based on a larger sample size of 2552 patients; thus, the analysis results were more persuasive to a certain degree. We carefully considered the definitions of complications; residual stones are not a complication but should be considered as a cure failure because they are not associated with PDC or other various BD methods after LCBDE. Considering that a number of postoperative complications were caused by T-tube dislodgement or planned removal, we attempted to evaluate the risk of bile leak or bile peritonitis when the T tube was indwelling and found that TTD had no valuable effect on preventing bile leak and bile peritonitis. We also analyzed the difference in the incidence of postoperative recurrent CBD stones and biliary stricture between the PDC/PDC+BD and TTD groups, which had not been reported in previous meta-analyses. The Peto OR was employed for comparing low incidence events, which may be the most effective method and was able to minimize bias. The OR distributions in the funnel plots for postoperative overall morbidity and bile leak were basically symmetrical, reflecting the relatively small bias in this meta-analysis.

In summary, PDC alone or PDC+BD yielded a significantly lower postoperative morbidity than did TTD. Decompression TTD did not seem to be effective in preventing the occurrence of bile leak or bile peritonitis; PDC+BD was a reasonable alternative if the condition was not suitable for PDC alone, eg, when biliary decompression was required. Furthermore, PDC and PDC+BD yielded a shorter surgical time and hospital stay and might be safe in terms of biliary stricture under a suitable CBD diameter. However, further large and well-designed randomized controlled trials that would evaluate the effectiveness and safety of various drainage methods after LCBDE are needed to confirm these findings.

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