# Comparison of Clinical Efficacy of Early Versus Delayed Laparoscopic Cholecystectomy Following Ultrasound-Guided Percutaneous Transhepatic Gallbladder Drainage

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AIM: To investigate the clinical value of early (≤7 days) versus delayed (>6 weeks) laparoscopic cholecystectomy (LC) after ultrasound-guided percutaneous transhepatic gallbladder drainage (PTGBD) in high-risk acute cholecystitis (AC), with PTGBD serving as a bridging intervention.
METHODS: A retrospective analysis was performed on 110 high-risk AC patients admitted between August 2021 and January 2025. Patients were divided into an early LC group (52 cases) and a delayed LC group (58 cases). Surgical indicators, inflammatory response control, hospitalization duration, treatment costs, quality of life, and postoperative complications were compared between the two groups.
RESULTS: The early LC group demonstrated significantly superior outcomes in operative time (22.51 ± 4.32 vs. 65.28 ± 15.12 minutes, $p < 0.001$), intraoperative blood loss (12.16 ± 2.13 vs. 52.47 ± 6.11 mL, $p < 0.001$), length of hospital stay (7.12 ± 0.58 vs. 10.11 ± 1.62 days, $p < 0.001$), and total treatment costs (2.36 ± 0.32 vs. 3.80 ± 0.52 ten thousand yuan, $p < 0.001$, 1 dollar = 6.91 yuan). The incidence of moderate to severe adhesions was significantly lower in the early LC group (28.85% vs. 56.90%, $p = 0.003$). However, the delayed LC group exhibited lower postoperative C-reactive protein levels (12.45 ± 2.23 vs. 15.32 ± 2.78 mg/L, $p < 0.001$) and procalcitonin levels (0.25 ± 0.06 vs. 0.38 ± 0.05 ng/mL, $p < 0.001$), as well as significantly higher quality-of-life scores at 3 months postoperatively (all $p < 0.001$). No statistically significant differences were observed in complication rates (9.62% vs. 15.52%) or conversion-to-laparotomy rates (3.85% vs. 10.34%) between groups ($p > 0.05$).
CONCLUSIONS: Early LC following PTGBD effectively shortens overall treatment duration, reduces healthcare costs, and lowers surgical complexity. However, careful consideration should be given to the potential influence of residual inflammation on long-term quality of life. Further multi-center prospective studies are warranted to validate long-term safety and to optimize individualized treatment strategies.

**Keywords:** laparoscopic cholecystectomy; percutaneous transhepatic gallbladder drainage; acute cholecystitis; clinical efficacy; timing of surgery

## Introduction

Acute cholecystitis (AC) is a common acute clinical condition of the abdomen. Laparoscopic cholecystectomy (LC), recognized as the "gold standard" treatment due to its minimally invasive and definitive nature, is widely accepted in clinical practice [1]. However, in high-risk patients with severe comorbidities or marked local inflammation, emergency LC is associated with significantly increased rates of conversion to open surgery and postoperative complications [2]. In this context, ultrasound-guided percutaneous transhepatic gallbladder drainage (PTGBD) serves as a transitional therapeutic option. By draining infected bile and controlling the progression of sepsis, PTGBD creates favorable conditions for subsequent definitive surgery [3,4]. However, PTGBD has inherent limitations: it cannot definitively cure cholecystitis, and patients still require a secondary procedure, namely, elective LC, to completely resolve the underlying pathology [5,6].

Traditional perspectives recommend delaying LC for 6–8 weeks after PTGBD to allow sufficient resolution of inflammation, thereby minimizing intraoperative adhesions and anatomical challenges [7–9]. Recent study, however, indicates that prolonged waiting periods may exacerbate gallbladder wall fibrosis, increase the technical complexity of LC, and be associated with catheter-related complications, such as displacement and infection, as well as re-

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current cholecystitis, with reported rates of up to 20%–30% [10]. Consequently, the concept of early LC (≤7 days post-PTGBD) has been proposed. Early surgical intervention utilizes the so-called "inflammatory window", characterized by reduced gallbladder edema before the formation of dense adhesions, to improve operative exposure, reduce conversion rates, shorten overall treatment duration, and minimize healthcare resource utilization. In the present study, the "inflammatory window" is defined, based on relevant literature [10,11] and clinical experience, as ≤7 days following PTGBD. Objective criteria for this period include ultrasonographic evidence of reduced gallbladder wall edema compared with the initial onset, absence of dense adhesions, and dynamic monitoring demonstrating ≥50% reduction in C-reactive protein (CRP) levels from the peak value without a continuous upward trend [12].

Although the Tokyo Guidelines 2018 recommend PTGBD as a bridging therapy for high-risk patients, they do not provide explicit guidance on the optimal timing of subsequent LC [13]. Current studies mainly focus on PTGBD combined with delayed LC (>6 weeks), while high-quality evidence on the safety, feasibility, and cost-effectiveness of early LC remains limited [14,15]. Therefore, this study adopts PTGBD as a standardized bridging intervention for high-risk AC patients and further compares the clinical value of early (≤7 days) LC versus conventional delayed LC (>6 weeks) following PTGBD, with the aim of providing evidence to optimize staged treatment strategies for AC.

## Methods

### *General Information*

This retrospective study enrolled 110 patients with AC admitted to Suizhou Central Hospital between August 2021 and January 2025. Based on the treatment strategy received, patients were divided into an early laparoscopic cholecystectomy (LC) group (52 cases) and a delayed LC group (58 cases). This study was conducted following the principles outlined in the Declaration of Helsinki and received ethical approval from the Ethics Committee of Suizhou Central Hospital (approval number: 2025008). All patients provided written informed consent after being fully informed of the research objectives.

### *Inclusion and Exclusion Criteria*

Inclusion criteria: ① diagnosis of AC according to the Tokyo Guidelines 2018 [16], including right upper quadrant pain, fever, a positive Murphy's sign, and imaging findings of gallbladder wall thickening >4 mm or pericholecystic fluid; ② age ≥18 years; ③ complete clinical data, including preoperative imaging, laboratory examinations, surgical records, and 3-month postoperative follow-up data.

Exclusion criteria: ① history of gallbladder cancer or other malignancies; ② pregnancy or concomitant acute abdomen (e.g., acute pancreatitis or intestinal perforation); ③ loss to follow-up or incomplete medical records; ④ contraindications to emergency LC, such as severe cardiovascular or cerebrovascular disease, pulmonary disease, or coagulation dysfunction.

During the study period, all eligible high-risk AC patients meeting the inclusion and exclusion criteria were consecutively enrolled. A total of 128 patients were admitted during this period, of whom 18 were excluded (3 cases with a history of gallbladder cancer, 2 cases of pregnancy, 5 cases with concomitant acute pancreatitis, and 8 cases lost to follow-up). Ultimately, 110 patients were included, ensuring the completeness and representativeness of the study sample.

### *Treatment Protocol*

Upon admission, all patients received antibiotics and systemic supportive therapy to protect organ function and maintain hemodynamic stability. In accordance with this institution's standards, PTGBD was performed on patients deemed to be at high surgical risk or who responded poorly to initial conservative treatment. PTGBD was performed within 24–48 hours by senior attending physicians. Patients were positioned to optimize visualization of the gallbladder along its long axis. Following local anesthesia with lidocaine and routine disinfection, a puncture needle was inserted through the liver into the gallbladder lumen under ultrasound guidance. Successful puncture was confirmed by the aspiration of pus or bile. A pigtail catheter was then advanced 2–3 cm to form a 5–6 cm loop within the gallbladder, fixed in place, and connected to a drainage bag. Bile samples were collected for bacterial culture and drug sensitivity testing. Postoperative monitoring included vital signs, drainage volume, and bile color, with timely management of potential complications, such as bleeding or bile leakage.

Patients in the early LC group underwent LC within 7 days after PTGBD, while those in the delayed LC group received LC >6 weeks post-PTGBD. LC was performed using a standardized three-port technique. Preoperative ultrasound and/or computed tomography (CT) were performed as clinically indicated to evaluate gallbladder morphology, gallbladder wall thickness, pericholecystic adhesions, and the presence of biliary duct dilation, thereby guiding surgical planning. After endotracheal intubation, the abdomen was disinfected, and a 1 cm incision was made above the umbilicus. A trocar was inserted under pneumoperitoneum at 12 mmHg, followed by placement of two additional ports at the subxiphoid region and right midclavicular line. The gallbladder triangle was carefully dissected, and the cystic duct and artery were ligated. The gallbladder was subsequently excised. In cases of gallbladder enlargement, bile aspiration was performed before removal. Conversion to open surgery was performed when anatomical structures were unclear, bleeding was difficult to control, or bile duct injury was suspected.

*Observational Indicators*

Baseline Data

Baseline characteristics included age, sex, body mass index (BMI), comorbidities (hypertension, diabetes mellitus, and hyperlipidemia), and the interval from symptom onset to diagnosis.

Surgical Indicators

(a) Operative time: defined as the duration from skin incision to skin closure, measured in minutes; (b) intraoperative blood loss: calculated as suction volume minus irrigation volume, expressed in milliliters (mL); (c) adhesion grading: assessed intraoperatively and categorized as none, mild, moderate, or severe. None indicated no adhesions; mild referred to easily separable adhesions involving structures such as the omentum or colon; moderate denoted partial adhesions involving the liver bed or duodenum requiring blunt dissection; and severe indicated dense adhesions. (d) Conversion rate: defined as the proportion of cases converted to open surgery because of severe adhesions or complex anatomical conditions, expressed as a percentage (%).

Recovery Indicators

(a) Inflammatory markers: white blood cell (WBC) count ($\times 10^9$/L), C-reactive protein (CRP, mg/L), and procalcitonin (PCT, ng/mL) measured before PTGBD and at 1 week after LC; (b) hospital stay: total length of hospitalization from admission to discharge (delayed LC group: cumulative days for two admissions); (c) total costs: overall treatment expenses, including surgical procedures, medications, imaging examinations, and hospitalization, expressed in ten thousand yuan (1 dollar = 6.91 yuan); (d) quality of life: evaluated using the 36-Item Short Form Health Survey (SF-36) scale, covering domains such as physical functioning, pain, and social functioning, assessed preoperatively and at 3 months postoperatively [17].

Safety

Total complication rate: included postoperative ascites, intestinal injury, and biliary tract injury. Specific definitions were as follows. Ascites was defined as a pathological accumulation of fluid in the abdominal cavity after surgery requiring puncture and drainage, excluding physiological postoperative reactive effusion. Intestinal injury referred to damage or perforation of the intestinal mucosa occurring during surgery and was classified as mild (superficial mucosal injury without the need for special repair, requiring only local treatment), moderate (full-thickness intestinal wall injury without perforation, requiring suture repair), and severe (intestinal wall perforation, requiring emergency surgical repair or intestinal resection with anastomosis). All grades of intestinal injury were included in the analysis, and injury severity and the need for additional intervention were recorded. Biliary tract injury was defined as damage to the integrity of biliary structures, including the cystic duct or common bile duct, and was categorized as mild (biliary mucosal injury without obvious bile leakage, recoverable with conservative treatment), moderate (partial biliary wall defect with limited bile leakage, requiring minimally invasive intervention such as endoscopic stent placement), or severe (complete biliary duct rupture or large-area defect requiring open surgical repair). All grades of biliary tract injury were included in the statistical analysis, with documentation of any additional therapeutic measures.

*Statistical Analysis*

Statistical analyses were performed using SPSS (version 26.0, IBM SPSS Statistics, Armonk, NY, USA) continuous variables were tested for normality using the Shapiro-Wilk test. Variables that conformed to a normal distribution were expressed as mean $\pm$ standard deviation and compared between groups using the independent samples $t$-test. Categorical variables were presented as frequencies and percentages (%) and analyzed using the chi-square or Fisher's exact test, as appropriate. A two-sided $p < 0.05$ is considered statistically significant.

## Results

*Baseline Characteristics*

A total of 110 patients with AC were included in the analysis, comprising an early LC group (52 cases) and a delayed LC group (58 cases). No significant differences were observed between the two groups in baseline characteristics, including age, sex, BMI, time from symptom onset to diagnosis, or comorbidities ($p > 0.05$ for all), indicating good comparability (Table 1).

*Surgical Outcomes*

The early LC group demonstrated a significantly shorter operative time (22.51 $\pm$ 4.32 vs. 65.28 $\pm$ 15.12 minutes, $p < 0.001$) and significantly reduced intraoperative blood loss (12.16 $\pm$ 2.13 mL vs. 52.47 $\pm$ 6.11 mL, $p < 0.001$) compared with the delayed LC group. Adhesions were predominantly none or mild in the early LC group (71.15%), whereas moderate to severe adhesions were more frequent in the delayed LC group (56.90%, $p$ = 0.003). Although the conversion-to-open-surgery rate was lower in the early LC group (3.85% vs.10.34%), the difference did not reach statistical significance ($p$ = 0.277) (Table 2).

*Inflammatory Markers*

Postoperative inflammatory markers, including WBC, CRP, and PCT, decreased significantly in both groups ($p < 0.05$ for all). However, postoperative WBC levels (7.25 $\pm$ 0.95 $\times 10^9$/L vs. 6.82 $\pm$ 1.02 $\times 10^9$/L, $p$ = 0.026), CRP levels (15.32 $\pm$ 2.78 mg/L vs. 12.45 $\pm$ 2.23 mg/L, $p < 0.001$) and PCT levels (0.38 $\pm$ 0.05 ng/mL vs. 0.25 $\pm$ 0.06 ng/mL, $p < 0.001$) remained higher in the early LC group than in the delayed LC group (Table 3).

**Table 1. Baseline clinical characteristics of the study population.**

| Variables | Early LC group (n = 52) | Delayed LC group (n = 58) | $t/\chi^2$ | $p$-value |
|---|---|---|---|---|
| Age (years) | 65.35 ± 8.62 | 66.66 ± 6.92 | –0.883 | 0.379 |
| Sex | | | 0.002 | 0.967 |
| Male | 28 (53.85%) | 31 (53.45%) | | |
| Female | 24 (46.15%) | 27 (46.55%) | | |
| BMI (kg/m$^2$) | 21.97 ± 2.70 | 21.61 ± 2.88 | 0.682 | 0.497 |
| Time from onset to diagnosis (days) | 2.17 ± 0.38 | 2.24 ± 0.43 | –0.875 | 0.384 |
| Comorbidities | | | | |
| Diabetes mellitus | 32 (61.54%) | 33 (56.90%) | 0.244 | 0.621 |
| Hypertension | 39 (75.00%) | 37 (63.79%) | 1.613 | 0.204 |
| Hyperlipidemia | 28 (53.85%) | 31 (53.45%) | 0.002 | 0.967 |

LC, laparoscopic cholecystectomy; BMI, body mass index.

**Table 2. Comparison of surgery-related variables.**

| Variables | Early LC group (n = 52) | Delayed LC group (n = 58) | $t/\chi^2$ | $p$-value |
|---|---|---|---|---|
| Surgery time (minutes) | 22.51 ± 4.32 | 65.28 ± 15.12 | –19.676 | <0.001 |
| Intraoperative blood loss (mL) | 12.16 ± 2.13 | 52.47 ± 6.11 | –45.116 | <0.001 |
| Adhesion grading | | | 8.771 | 0.003 |
| None/mild | 37 (71.15%) | 25 (43.10%) | | |
| Moderate/severe | 15 (28.85%) | 33 (56.90%) | | |
| Conversion to laparotomy | 2 (3.85%) | 6 (10.34%) | - | 0.277 |

Note: "-" indicates that Fisher's exact test was used; therefore, no $t$ or $\chi^2$ value is reported.

**Table 3. Comparison of inflammatory markers before PTGBD and after laparoscopic cholecystectomy.**

| Group (n) | WBC (×10$^9$/L) | | CRP (mg/L) | | PCT (ng/mL) | |
|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After |
| Early LC group (n = 52) | 14.35 ± 2.12 | 7.25 ± 0.95* | 127.65 ± 15.23 | 15.32 ± 2.78* | 1.42 ± 0.22 | 0.38 ± 0.05* |
| Delayed LC group (n = 58) | 13.98 ± 2.45 | 6.82 ± 1.02* | 126.78 ± 14.56 | 12.45 ± 2.23* | 1.37 ± 0.23 | 0.25 ± 0.06* |
| $t$-value | 0.825 | 2.264 | 0.307 | 5.995 | 1.083 | 12.006 |
| $p$-value | 0.411 | 0.026 | 0.760 | <0.001 | 0.281 | <0.001 |

Note: * indicates a statistically significant difference compared with the preoperative value within the same group ($p < 0.05$).
PTGBD, percutaneous transhepatic gallbladder drainage; WBC, white blood cell; CRP, C-reactive protein; PCT, procalcitonin.

**Table 4. Comparison of the length of hospital stay and treatment costs.**

| Variables | Early LC group (n = 52) | Delayed LC group (n = 58) | $t/\chi^2$ | $p$-value |
|---|---|---|---|---|
| Length of hospital stay (days) | 7.12 ± 0.58 | 10.11 ± 1.62 | –12.563 | <0.001 |
| Total treatment cost (ten thousand yuan) | 2.36 ± 0.32 | 3.80 ± 0.52 | –17.207 | <0.001 |

1 dollar = 6.91 yuan.

*Hospital Stay and Costs*

Patients in the early LC group had significantly shorter hospital stays (7.12 ± 0.58 vs. 10.11 ± 1.62 days, $p < 0.001$) and lower total treatment costs (2.36 ± 0.32 vs. 3.80 ± 0.52 ten thousand yuan, $p < 0.01$) compared with those in the delayed LC group (Table 4).

*Quality-of-Life Scores*

At 3 months postoperatively, patients in the delayed LC group exhibited notably higher SF-36 scores across multiple domains, including physical functioning, bodily pain, and mental health, compared with the early LC group ($p < 0.001$ for all) (Table 5).

*Postoperative Complications*

The overall complication rate was lower in the early LC group (9.62%, 5/52) than in the delayed LC group (15.52%, 9/58). However, the difference was not statistically significant ($p$ = 0.354) (Table 6).

## Discussion

AC is a common hepatobiliary disorder, predominantly caused by gallstone impaction. Inadequate or delayed management may result in severe complications, including gallbladder gangrene, perforation, and potentially life-threatening conditions. Previous studies have reported complication rates ranging from 7% to 26% and an over-

**Table 5. Comparison of SF-36 quality-of-life scores before and after surgery (mean ± standard deviation, points).**

| Dimension | Early LC group (n = 52) | Delayed LC group (n = 58) | *t* | *p* | Early LC group (n = 52) | Delayed LC group (n = 58) | *t* | *p* |
|---|---|---|---|---|---|---|---|---|
| | Before | | | | After | | | |
| Physiological function | 61.65 ± 6.47 | 61.21 ± 6.59 | 0.345 | 0.731 | 70.89 ± 6.78* | 81.31 ± 7.61* | –7.543 | <0.001 |
| Physiological role | 60.72 ± 6.21 | 61.07 ± 6.61 | –0.291 | 0.771 | 70.88 ± 6.54* | 81.31 ± 7.60* | –7.668 | <0.001 |
| Somatic pain | 61.58 ± 6.49 | 61.21 ± 6.52 | 0.298 | 0.766 | 70.86 ± 6.41* | 81.12 ± 7.28* | –7.815 | <0.001 |
| General health | 59.92 ± 6.64 | 60.44 ± 6.22 | –0.414 | 0.680 | 71.14 ± 6.71* | 81.21 ± 7.53* | –7.364 | <0.001 |
| Vitality | 61.27 ± 5.83 | 60.81 ± 6.54 | 0.386 | 0.700 | 70.67 ± 6.44* | 80.91 ± 7.32* | –7.752 | <0.001 |
| Social function | 61.37 ± 6.26 | 60.78 ± 6.42 | 0.486 | 0.628 | 70.87 ± 6.38* | 81.08 ± 7.45* | –7.668 | <0.001 |
| Emotional function | 60.55 ± 6.34 | 61.16 ± 6.19 | –0.515 | 0.607 | 70.79 ± 6.72* | 81.34 ± 7.35* | –7.832 | <0.001 |
| Mental Health | 61.07 ± 6.41 | 60.64 ± 6.85 | 0.346 | 0.730 | 76.25 ± 7.20* | 85.88 ± 8.11* | –6.555 | <0.001 |

Note: * indicates a statistically significant difference compared with the preoperative value within the same group ($p < 0.05$). SF-36, 36-Item Short Form Health Survey.

**Table 6. Comparison of postoperative complications [n (%)].**

| Group (n) | Ascites | Intestinal injury | Biliary tract injury | Overall complication rate |
|---|---|---|---|---|
| Early LC group (n = 52) | 1 (1.92%) | 2 (3.85%) | 2 (3.85%) | 5 (9.62%) |
| Delayed LC group (n = 58) | 3 (5.17%) | 2 (3.45) | 4 (6.90%) | 9 (15.52%) |
| $\chi^2$ | | | | 0.860 |
| *p*-value | | | | 0.354 |

all mortality rate of approximately 10%, underscoring the substantial clinical burden and safety risks associated with AC [18,19]. Laparoscopic cholecystectomy (LC), as the gold standard for the treatment of calculous cholecystitis, offers definitive management of benign gallbladder disease. However, the optimal timing of LC remains controversial and has significant implications for perioperative outcomes.

The present study confirms the advantages of early LC in improving surgical efficiency and reducing healthcare resource utilization, as evidenced by a 64% reduction in operative time (22.51 ± 4.32 vs. 65.28 ± 15.12 minutes) and a 77% decrease in intraoperative blood loss (12.16 ± 2.13 mL vs. 52.47 ± 6.11 mL). Moreover, the markedly lower proportion of moderate to severe adhesions in the early LC group (28.85% vs. 56.90%) supports the "inflammatory window" hypothesis. During this phase, partial resolution of gallbladder edema occurs before the development of dense fibrotic adhesions, thereby facilitating clearer anatomical identification and safer dissections. Conversely, delayed LC was associated with superior inflammatory control, as demonstrated by significantly lower postoperative WBC levels (7.25 ± 0.95 $\times 10^9$/L vs. 6.82 ± 1.02 $\times 10^9$/L, $p = 0.026$), CRP levels (12.45 ± 2.23 vs. 15.32 ± 2.78 mg/L, $p < 0.001$) and PCT levels (0.25 ± 0.06 vs. 0.38 ± 0.05 ng/mL, $p < 0.001$), as well as higher SF-36 quality-of-life scores at 3 months postoperatively. These findings suggest that the advantages observed in the delayed LC group in terms of inflammatory markers and quality of life may be influenced by multiple factors. Specifically, patients in the delayed group benefited from a longer physiological recovery period, improved nutritional status, and gradual psychological adaptation during the waiting interval, rather than these outcomes being attributed solely to the timing of surgery. In addition, the shorter hospitalization time in the early LC group may have limited the intensity and continuity of postoperative rehabilitation guidance, which could also influence longer-term quality-of-life outcomes. Notably, although differences in overall complication rates (9.62% vs. 15.52%) and conversion-to-open surgery rates (3.85% vs. 10.34%) did not reach statistical significance, the numerically lower rates observed in the early LC group warrant clinical consideration.

An increasing body of literature supports shortening the interval between PTGBD and subsequent LC. For example, Lee *et al*. [11] proposed that PTGBD performed within 3.5 days of symptom onset in patients with Grade I AC reduced surgical difficulty, with LC undertaken within 7.5 days post-PTGBD yielding optimal outcomes. However, concerns remain regarding residual inflammation during early LC. Wang *et al*. [12] suggested that surgery performed in the acute phase may increase the risk of intraoperative bleeding or tissue injury due to the heightened tissue fragility. In the present study, these risks were likely mitigated by strict patient selection, excluding cases with extensive gallbladder necrosis or gangrene, and the involvement of experienced surgeons. The lower postoperative CRP and PCT levels observed in the delayed LC group are consistent with the findings of Kimura *et al*. [20], indicating that prolonged waiting may facilitate more complete resolution of local inflammation. However, excessive delays are not without drawbacks. In this study, delayed LC was associated with a 42% longer hospital stay (10.11 ± 1.62 vs. 7.12

± 0.58 days) and a 61% increase in total treatment costs (3.80 ± 0.52 vs. 2.36 ± 0.32 ten thousand yuan), conflicting with demands for improved healthcare efficiency and cost containment.

For high-risk patients with severe comorbidities, early LC minimizes the risks of rehospitalization and PTGBD catheter-related complications, such as catheter displacement and infection, while reducing the duration of antibiotic therapy and the potential for antimicrobial resistance. Its economic advantage, reflected by a 38% reduction in total costs, is particularly relevant in resource-limited healthcare settings. Technically, early LC requires precise dissection of Calot's triangle and therefore depends on adequate surgeon experience and proficiency. The low conversion-to-open surgery rate (3.85%) observed in the early LC group further supports the technical feasibility of this approach when strict patient selection criteria are applied.

The relatively higher postoperative CRP and PCT levels observed after early LC may reflect residual acute inflammatory activity. However, the absence of corresponding increases in clinical complications suggests that a certain degree of residual inflammation is clinically acceptable. Conversely, the superior postoperative quality-of-life scores observed in the delayed LC group may stem from extended recovery periods, improved nutritional status, and psychological adaptation. Additionally, the shorter hospitalization duration associated with early LC may limit the depth and continuity of postoperative rehabilitation guidance, highlighting the need for optimized postoperative care pathways.

Several limitations of this study should be acknowledged. As a single-center retrospective analysis with a relatively small sample size (n = 110) and a non-randomized design, the study is subject to potential selection bias. Moreover, no formal sample size calculation or power analysis was conducted. Although baseline characteristics did not exhibit statistically significant differences between the two groups, numerical imbalances may still introduce residual confounding. This limitation highlights the need for multicenter, large-sample prospective studies to further verify the generalizability of the present findings. Additionally, the relatively short 3-month follow-up period precludes adequate assessment of long-term risks, such as biliary stricture formation and disease recurrence. The absence of subjective pain assessments and functional recovery indicators, including bile excretion capacity, has led to an underestimation of clinically meaningful differences between treatment strategies. Therefore, future multi-center randomized controlled trials are warranted to validate long-term safety and to explore stratified therapeutic strategies based on the severity of inflammation. Furthermore, health-economic analyses quantifying the balance between resource savings associated with early LC and quality-of-life benefits observed with delayed LM may provide valuable evidence for policy and decision-making. The development of predictive tools, such as CT or magnetic resonance imaging (MRI)-based inflammatory scoring systems, is also crucial for identifying patients most suitable for early LC.

Clinical Implications: Early LC may be preferred for clinically stable patients with localized inflammation, while delayed LC may be more appropriate for individuals with extensive necrosis, suppurative cholangitis, or severe comorbidities. Incorporation of high-quality evidence on early LC into future revisions of the Tokyo Guidelines could help refine recommendations for the optimal timing of surgery. Multidisciplinary collaboration and dynamic imaging-based assessments remain essential for optimizing individualized surgical decision-making.

## Conclusions

Early LC offers a safe and effective therapeutic option for high-risk AC patients by shortening overall treatment duration, reducing healthcare costs, and lowering intraoperative complexity. Although early LC may be slightly inferior to delayed LC in terms of inflammatory control and long-term quality of life, it offers significant overall clinical and economic benefits. Future high-quality studies are required to validate long-term outcomes and advance personalized treatment strategies.

## Availability of Data and Materials

The data analyzed are available from the corresponding authors upon reasonable request.

## Author Contributions

SX and PZ conceived and designed the research, performed the experiments, collected and analyzed the data. RL and GZ equally contributed to the study design and data analysis and drafted the manuscript. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

## Ethics Approval and Consent to Participate

The study was conducted following the principles outlined in the Declaration of Helsinki and obtained ethical approval from the Ethics Committee of Suizhou Central Hospital (approval number: 2025008). All patients provided written informed consent being fully informed of the research objectives.

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## Conflict of Interest

The authors declare no conflict of interest.

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