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Original Article

Predictive and prognostic factors associated with unliquefied pyogenic liver abscesses

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Abstract *Introduction:* Poor liquefaction of pyogenic liver abscesses, which makes drainage impossible at the time of diagnosis, is not infrequent. The impact of poor liquefaction and subsequent drainage failure on clinical outcomes is unknown.
Methods: We conducted a retrospective study with all patients diagnosed with liver abscesses from July 2017 through June 2020. Late drainage (LD) was defined as drainage performed ≥48 h after diagnosis due to poor liquefaction. Logistic regression was performed to identify the factors associated with late or non-drainage (LD/ND). The Cox proportional hazard model was used to identify the variables related to abscess recurrence by 90 days after diagnosis.
Results: A total of 153 patients were included. Thirty (19.6%) patients underwent LD and 54 (35.3%) did not undergo drainage. Other than non-cystic appearance, LD/ND was associated with smaller size (adjusted odds ratio [aOR] 0.85, 95% confidence interval [CI] 0.73–0.98, $p = 0.031$) and culture-negativity (aOR 2.69, 95% CI 1.14–6.67, $p = 0.027$). Current hepatopancreaticobiliary malignancy was the only significant predictor of 90-day recurrence. Neither LD/ND (OR, 0.56; 95% CI, 0.13–2.41; $p = 0.426$) nor LD (OR, 1.26; 95% CI, 0.23–5.55; $p = 0.719$) was associated with recurrence by 90 days. The incidence of late complications was reduced by drainage, without a reduction in the duration of hospitalization.

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Conclusion: Several clinical features were associated with undrainable liver abscesses. Neither LD/ND nor ND had an adverse impact on clinical outcomes.

Introduction

Despite a marked decrease in the incidence of amoebic liver abscesses, pyogenic liver abscesses continue to affect people with various conditions, especially in the Far East.[1] In particular, in this region, cryptogenic liver abscesses due to *Klebsiella pneumoniae* have increased over the last several decades.[2,3] Pyogenic liver abscesses are treated with percutaneous drainage or aspiration and a prolonged course of antibiotics.[4] Surgery is now rarely performed since non-surgical drainage has been proven safe and effective.[5] Despite the importance of rapid source control in this serious infection, early drainage at the time of diagnosis is often not possible due to poor liquefaction. Radiologists in Hong Kong and Singapore reported that *K. pneumoniae* liver abscesses tended to look solid on ultrasonography and computed tomography (CT), possibly due to the resistance to phagocytosis of the bacterial serotype common in those areas.[6,7] Clinical improvement may be delayed without early drainage and if the lesion remains undrained, there is a concern for the possibility of relapse. For these reasons, unliquefied abscesses often lead to repetitive imaging tests to evaluate the feasibility of later drainage and the treatment response, which may lead to increased medical costs.[3,8] However, little is known about the factors associated with the failure of early drainage due to poor liquefaction and its impact on clinical outcomes.[9,10] Thus, we aimed to investigate the clinical characteristics associated with poor liquefaction at the time of liver abscess diagnosis and the impact of late or non-drainage on the clinical outcomes.

Methods

Study population and data acquisition

The electronic medical records of all patients who were admitted with a diagnosis of a liver abscess from July 2017 to June 2020 at Samsung Medical Center, a 1950-bed tertiary referral center in South Korea, were retrospectively reviewed. The diagnosis of a liver abscess was made by the presence of at least one compatible symptom (fever, chills, right upper quadrant or epigastric pain, nausea, vomiting, or diarrhea) and radiologic findings compatible with a liver abscess. The exclusion criteria were 1) patients who did not undergo drainage due to reasons other than poor liquefaction, such as the small size (<3 cm) of the lesion or technical difficulty regarding the location of the lesion, 2) patients whose lesions were later proven to be malignant by biopsy, 3) patients who died within 48 h after diagnosis, and 4) patients with limited life expectancy due to underlying disease. Patients who died within 48 h after diagnosis were excluded because early drainage was unlikely to affect their prognosis. Those who did not have outpatient follow-up before 90 days after diagnosis were contacted by phone. The subjects with neither information on outcome nor response to calls were also excluded. This study was approved by the Institutional Review Board of Samsung Medical Center with a waiver of informed consent (IRB No: 2021-07-043-002).

The study population was divided according to two criteria: 1) whether an abscess was found liquefied on the image taken at the first visit and drained within 48 h after diagnosis (early drainage [ED] group) or liquefied on one of the follow-up images and subsequently drained during hospitalization (late drainage [LD] group) and 2) whether the abscess was drained anytime from diagnosis to discharge (drainage [D] group) or not drained until discharge (non-drainage [ND] group).

Information regarding demographics, comorbidities, vital signs, initial and follow-up abdominal imaging findings, laboratory test results, bacterial isolates from blood and abscesses and their antimicrobial susceptibility profile, and the name and duration of antibiotics were collected. The primary outcome was abscess recurrence by 90 days after diagnosis. Thirty-day mortality, 90-day mortality, complications that occurred later than 48 h after diagnosis, transfer to the intensive care unit (ICU), length of the ICU stay, total hospital stay length, and the duration of antibiotic use were compared as secondary outcomes.

Definitions

The definition of a current malignancy followed the International Classification of Diseases, 10th Revision, Clinical Modification (ICD-10-CM) official guidelines for coding and reporting 2010.[11] Major organ failure, abscess rupture, the development of complicated pleural effusion requiring drainage, and metastatic infection that occurred within 48 h of treatment were defined as early complications. The same conditions occurred later than 48 h after diagnosis as late complications. Major organ failure included acute kidney injury, acute liver failure, acute respiratory failure, and acute heart failure. The definition of acute kidney injury followed the Kidney Disease Improving Global Outcomes (KDIGO) guidelines.[12] Acute liver failure was defined as the development of hepatic encephalopathy and coagulopathy within 24 weeks of onset.[13] The definition of acute respiratory failure followed the British Thoracic Society guidelines.[14] Acute heart failure was defined as gradual or rapid changes in heart failure signs and symptoms resulting in a need for urgent therapy.[15] The Sequential Organ Failure Assessment score (SOFA) score and Charlson comorbidity index were used as defined previously.[16,17]

Radiologic evaluation

There is no international consensus on the radiological definition of abscess liquefaction. Therefore, the decision to

drain or not was made by the attending interventional radiologist on call. Solid/cystic appearance and the presence of septation are known as the two main determinants of liquefaction and the feasibility of successful drainage. For this study, a board-certified diagnostic radiologist specializing in abdominal imaging retrospectively reviewed all the images and evaluated lesions with the following criterion for "cystic appearance": the presence of non-enhancing or markedly hypodense areas constituting over 50% of the abscess volume.

Statistical analysis

The continuous variables were compared by the Student's *t*-test or Mann—Whitney *U* test and categorical variables by the chi-squared test or Fisher's exact test. To identify the predictive factors of LD/ND or ND, variables with a *p*-value less than 0.1 were further examined by logistic regression with backward selection. The Cox proportional hazard model with backward selection was used to elucidate the independent factors associated with the primary outcome. Clinical characteristics and outcome variables were compared between 1) LD/ND versus ED group and 2) ND versus D group. "LD/ND" and "ND" variables were forced into the Cox hazard model. A two-sided *p*-value of <0.05 was considered statistically significant. All statistical analyses were performed using R software (version 4.1.1, R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline characteristics

A total of 153 patients were included (Fig. 1). Fourty-five patients (29.4%) presented with poorly liquefied abscesses and did not undergo drainage until discharge (ND group). Among 108 patients whose abscesses were drained (D group), 30 (27.8%) underwent late drainage (LD group). Among those who underwent drainage, pigtail catheter drainage was done in 93 (86.1%), and aspiration was done in 15 (13.9%). Out of 15 patients who underwent aspiration, 14 were classified as the ED group.

The baseline characteristics of the total study population are presented in Table 1. The study population mostly consisted of elderly males (median age, 66 years; male gender, 71.2%). The median time from symptom onset to diagnosis was four days (interquartile range [IQR] 1—7 days) and the median abscess diameter was 6.0 cm (IQR 4.6—7.8 cm). Cystic appearance was found in 73.9% and septation in 67.3%. Eighty-three (73.5%) out of 113 cystic abscesses also had septation. Among these, 34 (41.0%) cases were not feasible for ED. The most common comorbidity was diabetes mellitus (DM) (31.4%), followed by current malignancy at 22.9% (hepatopancreaticobiliary [HPB] malignancy, 17.0%). The median SOFA score was 3 (IQR 1—6) and bloodstream infection was present in 50.3%.

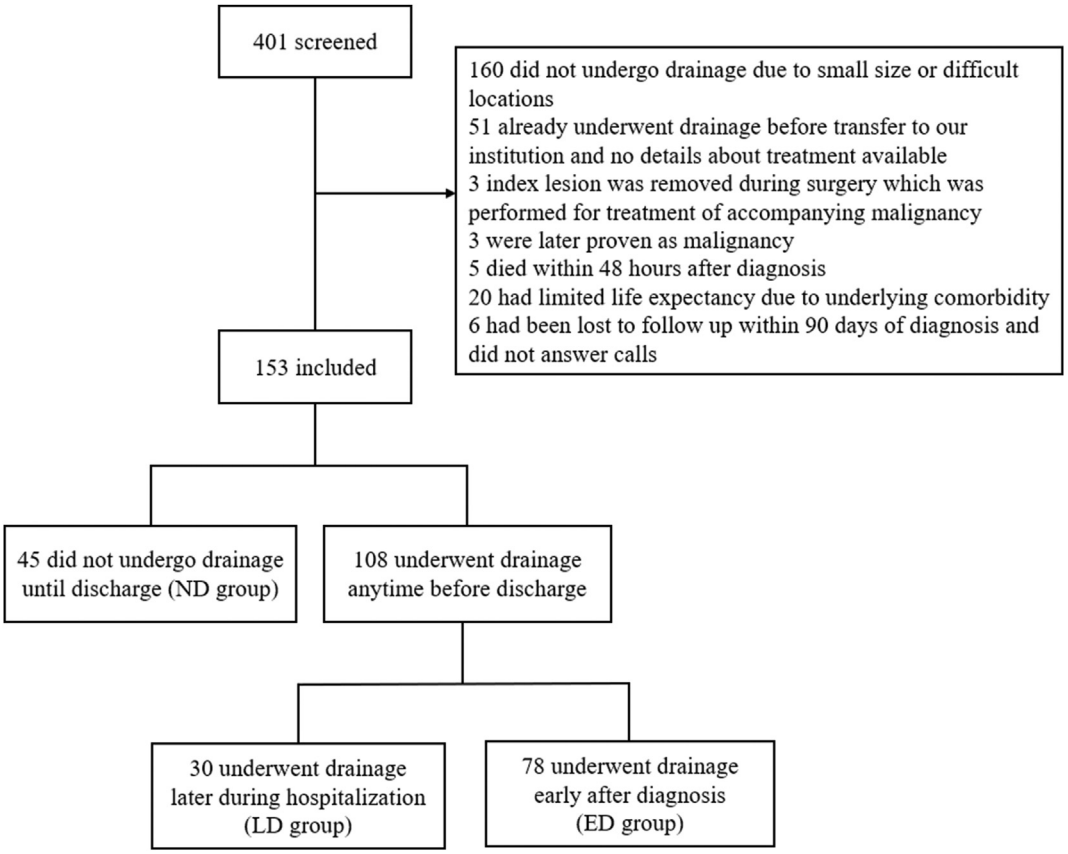

Figure 1. Study population.

CT was used as the imaging modality at diagnosis in all subjects. Follow-up imaging was performed in 82.7%, among which, ultrasonography was used in 69.4% of the cases. The median number of follow-up images was 1 (IQR 1—2) and the median time to the last follow-up image was eight days (IQR 6—13).

Since the radiologic characteristics of liver abscesses by *K. pneumoniae* are reported to differ from liver abscesses by other bacteria, we divided the study population by the etiologic microorganism (*K. pneumoniae* infections versus non-*K. pneumoniae* infections) and compared the two groups. There were no significant differences in the number of lesions, largest diameter, the proportion of lesions with cystic appearance, and those with septation (Supplementary Table 1).

Factors associated with liquefaction and drainage

Smaller diameter of the largest lesion (median 5.1 cm versus 7.0 cm, $p < 0.001$), higher Charlson comorbidity index (CCI) (median 4 versus 3, $p < 0.001$), lower erythrocyte sedimentation rate (ESR) (median 67 mm/h versus 91 mm/h, $p = 0.006$), lower C-reactive protein (CRP) concentrations (median 15.4 mg/dL versus 19.4 mg/dL, $p = 0.010$), polymicrobial infection (8.0% versus 19.2%, $p = 0.004$), and culture-negativity (36.9% versus 12.5%, $p < 0.003$) were associated with late drainage in univariate analysis (Table 2). After adjusting for confounders, smaller diameter of the largest lesion (adjusted odds ratio [aOR] 0.82, 95% confidence interval [CI]: 0.69—0.96, $p = 0.019$), and culture-negativity (aOR 5.18, 95% CI: 1.94—15.78, $p = 0.002$) were significant risk factors for LD/ND. Comorbidity and the proportion of *K. pneumoniae* infections did not differ between the LD/ND and the ED group.

When the ND group was compared to the D group, smaller abscess diameters (median 4.5 cm versus 7.0 cm, $p < 0.001$), presence of gas (2.2% versus 18.5%, $p = 0.008$), chronic kidney disease (8.9% versus 0.9%, $p = 0.026$), current HPB malignancy (2.2% versus 23.1%, $p = 0.002$), and lower ESR (median 61 mm/h versus 89 mm/h, $p = 0.007$) were associated with non-drainage (Table 3). In addition, current HPB malignancy (2.2% versus 23.1%, $p = 0.002$) and polymicrobial infection (4.4% versus 17.6%, $p = 0.038$) had inverse associations with non-drainage. On multivariable analysis, abscess size (aOR 0.63, 95% CI: 0.49—0.77, $p < 0.001$) and current HPB malignancy (aOR 0.07, 95% CI: 0.004—0.39, $p = 0.013$) were independently associated with non-drainage.

Clinical outcomes

The differences in clinical outcomes between the groups are presented in Table 4. The primary outcome occurred in 7 patients (4.6%). There was no difference in the incidence of the primary outcome between the LD/ND group and the ED group (2.7% versus 6.4%, OR 0.05—2.11, $p = 0.443$). No difference in any clinical outcome measures was noted between the LD and ED groups. The incidence of late complications and transfer to the ICU later than 48 h after diagnosis was lower compared to early complications and admission to the ICU within 48 h after diagnosis. When the ND group was compared to the D group, there was no significant difference in the primary outcome (4.4% versus 4.6%, $p > 0.999$). Clinical outcome measures except total hospital stay were comparable between the ND group and the D group.

Current malignancy (71.5% versus 20.5%, $p = 0.007$), current HPB malignancy (57.1% versus 15.1%, $p = 0.007$), and higher CCI (median 6 versus 3, $p = 0.019$) were associated with the incidence of the primary outcome (Table 5). After adjusting for confounders, current HPB malignancy was the only significant predictor of 90-day recurrence. Drainage and its timing were not associated with the primary outcome. The log-rank test did not reveal a significant difference between the groups (LD/ND group versus ED group, $p = 0.26$; ND group versus D group, $p = 0.88$) (Fig. 2). Due to the concern of aspiration being inferior to pigtail catheter placement, the method of source control was compared between the recurrence and non-recurrence groups. As presented in Table 5, those who underwent aspiration were more likely to experience abscess recurrence within 90 days (28.6% vs. 8.9%), but this was not statistically significant ($p = 0.141$).

Discussion

We identified several clinical characteristics associated with the failure to drain due to poor liquefaction of liver abscess. Nevertheless, neither LD/ND nor ND adversely impacted the clinical outcome primarily measured by recurrence by 90 days after diagnosis. Rather, comorbidity (i.e., HPB malignancy) had significant associations with the primary outcome.

The predictive factors of liver abscess drainage have rarely been studied. To our knowledge, there is only one study regarding this topic.[9] That study, in which 68% of the study population had amoebic abscesses, identified several characteristics associated with the feasibility of aspiration such as a larger size and seven days or longer time to diagnosis, which is consistent with our results. In our study, although lacking statistical significance, a shorter time from symptom onset to diagnosis was predictive of LD/ND, which is biologically plausible. Our study population had a shorter time to diagnosis compared to that of the abovementioned study (seven days or longer duration of symptoms: 37.9% versus 68.3%). Easier access to healthcare systems and earlier diagnosis may find more undrainable liver abscesses. Therefore, clinicians should be familiar with such presentations.

Various factors including abscess size, comorbidities, and etiologic microbial agents were associated with non-drainage. It was suggested that *K. pneumoniae* liver abscesses tend to be less liquefied at presentation, possibly due to the resistance to phagocytosis of the bacterial serotypes prevalent in the Far East.[6,7] However, our findings of similar size and proportion of cystic and septated lesions were inconsistent with the previous reports. This may be explained by the difference between the study populations (e.g., different comorbidities). The presence of HPB malignancy is likely to result in biliary tree obstruction and/or communication with the biliary tree, providing a portal of entry for bacteria. This may explain not only why the

Table 1 Baseline characteristics of the total study population.

Characteristics	N (%) or median (IQR) N = 153
Demographics	
Age (years)	66 (59, 73)
Male gender	109 (71.2%)
Symptoms	
Fever	141 (92.2%)
Right upper quadrant pain	86 (56.2%)
Nausea, vomiting or diarrhea	35 (22.9%)
Symptom onset to diagnosis (days)	4 (1, 7)
Radiologic findings	
Diameter of largest lesion (cm)	6.0 (4.6, 7.8)
Number of lesions	1 (1, 2)
Cystic appearance	113 (73.9%)
Presence of septation	103 (67.3%)
Presence of gas	21 (13.7%)
Presence of thrombophlebitis	25 (16.3%)
Comorbidities	
Diabetes mellitus	48 (31.4%)
Chronic kidney disease	5 (3.3%)
Liver cirrhosis	15 (9.8%)
Benign biliary disease	15 (9.8%)
Current malignancy	35 (22.9%)
Current HPB malignancy	26 (17.0%)
Receipt of liver transplantation	8 (5.2%)
Charlson comorbidity index	3 (2, 5)
Severity of infection	
SOFA score (n = 149)	3 (1, 6)
Admission to ICU within the first 48 h	25 (16.3%)
Early complications	49 (32.0%)
Laboratory findings	
White blood cell count (/μL) (n = 152)	13,480 (985, 17,490)
Erythrocyte sedimentation rate (mm/hour) (n = 128)	79 (51, 102)
C-reactive protein (mg/dL) (n = 151)	17.4 (11.2, 25.5)
Total bilirubin (mg/dL) (n = 152)	1.3 (0.8, 1.9)
Aspartate transaminase (U/L) (n = 152)	59 (36, 111)
Alanine transaminase (U/L) (n = 152)	61 (36, 108)
Alkaline phosphatase (U/L) (n = 139)	181 (110, 296)
Microbiologic findings	
Bacteremia	77 (50.3%)
Etiologic agent	
Klebsiella pneumoniae infection	84 (54.9%)
Escherichia coli infection	21 (13.7%)
Polymicrobial infection	21 (13.7%)
Culture-negative	35 (22.9%)
Use of appropriate empirical antibiotics (n = 117)[a]	110 (94.0%)

[a] Only culture-positive cases with available antimicrobial susceptibility test results were included.
All continuous variables are presented as the median with the interquartile range. All categorical variables are presented as the number with the percentage.
Abbreviation: HPB, hepatopancreaticobiliary; SOFA, Sequential Organ Failure Assessment; ICU, intensive care unit.

patients with HPB malignancy were more likely to undergo drainage in an attempt to control the infection sources, but also why they experienced more abscess recurrence. Additionally, the numerically higher mortality in the D group than in the ND group may be explained by the higher proportion of HPB malignancy in the D group. Yeh and coworkers reported that liver abscesses that occurred in patients with HPB malignancies had a lower chance of favorable outcomes than those that occurred in non-HPB malignancy patients.[18] In addition, the failure of percutaneous drainage, which was defined as surgical intervention or death, was frequent in patients with HPB malignancy, possibly due to communication with the biliary tree.[19]

A liver abscess is a serious infection commonly leading to sepsis, and Surviving Sepsis Campaign guidelines recommend that infection sources are controlled as soon as possible.[20] In general, previous studies have reported better outcomes with abscess drainage. Two studies performed with *K. pneumoniae* liver abscess patients suggested the benefit of early drainage within 3 days in terms of reduced mortality or a composite outcome including mortality.[10,21] More recent studies demonstrated fewer complications[22] and the earlier normalization of body temperature and CRP levels[23] in those managed with percutaneous drainage or aspiration than in medically managed patients. However, our study did not find significant harm from late or non-drainage. A possible reason for this was the exclusion of patients whose reason for not undergoing drainage was other than poor liquefaction. Although there have been no studies regarding the natural course of unliquefied liver abscesses, it is reasonable to assume that antibiotic penetration into an early abscess lesion is less compromised before the formation of walled-off necrosis. Therefore, these infections might have been able to resolve with medical management only.

Our study had several limitations. Since this was a single-center retrospective study, there might have been unadjusted confounders and it may be difficult to generalize the results of the present study to a wider population. Some of the confounders that could not have been adjusted due to the retrospective nature are as follows. First, ultrasonography, which was the main imaging modality of drainage

Table 2 Characteristics of the late drainage and non-drainage (LD/ND) versus early drainage (ED) groups.

	LD/ND (n = 75)	ED (n = 78)	OR	*p*-value	Adjusted OR	*p*-value
Demographics						
Age (years) (mean, SD)	66 (57, 75)	65 (60, 71)		0.971		
Male gender	58 (77.3%)	51 (65.4%)	1.79 (0.88—3.73)	0.103		
Radiologic findings						
Symptom onset to diagnosis (days)	3 (1, 7)	5 (2, 8)		0.084		
Diameter of largest lesion (cm)	5.6 (4.0, 7.0)	7.0 (5.2, 8.2)		<0.001	0.82 (0.69—0.96)	0.019
Number of lesions	1 (1, 1)	1 (1, 2)		0.628		
Cystic appearance	41 (54.7%)	72 (92.3%)	0.10 (0.04—0.25)	<0.001		
Presence of septation	53 (70.7%)	50 (64.1%)	1.34 (0.68—2.68)	0.387		
Presence of gas	6 (8.0%)	15 (19.2%)	0.37 (0.12—0.99)	0.044		
Presence of thrombophlebitis	12 (16.0%)	13 (16.7%)	0.95 (0.40—2.28)	0.911		
Comorbidities						
Diabetes mellitus	23 (30.7%)	25 (32.1%)	0.94 (0.47—1.87)	0.854		
Chronic kidney disease	4 (5.3%)	1 (1.3%)	3.91 (0.53—108.61)	0.204		
Liver cirrhosis	10 (13.3%)	5 (6.4%)	2.20 (0.73—7.58)	0.150		
Benign biliary disease	7 (9.3%)	8 (10.3%)	0.90 (0.30—2.70)	0.848		
Current malignancy	17 (22.7%)	18 (23.1%)	0.98 (0.45—2.10)	0.952		
Current HPB malignancy	10 (13.3%)	10 (20.5%)	0.60 (0.24—1.42)	0.237		
Receipt of liver transplantation	5 (6.7%)	3 (3.8%)	1.75 (0.40—9.33)	0.489		
Charlson comorbidity index	4 (2, 6)	3 (2, 5)		0.445		
Severity of infection						
SOFA score (n = 149)	3 (1, 6)	2 (1, 6)		0.668		
Admission to ICU within the first 48 h	8 (10.7%)	17 (21.8%)	0.43 (0.16—1.06)	0.063		
Early complications[a]	26 (34.7%)	23 (29.5%)	1.27 (0.64—2.52)	0.492		
Laboratory findings						
White blood cell count (/μL) (n = 152)	12,970 (9400, 15,840)	14,400 (10,480, 18,440)		0.170		
Erythrocyte sedimentation rate (mm/hour) (n = 128)	67 (38, 97)	91 (60, 110)		0.011	0.99 (0.98—1.00)	0.057
C-reactive protein (mg/dL) (n = 151)	16.2 (10.2, 22.0)	19.4 (12.8, 27.8)		0.010		
Total bilirubin (mg/dL) (n = 152)	1.3 (0.8, 2.3)	1.1 (0.8, 1.7)		0.546		
Aspartate transaminase (U/L) (n = 152)	53 (35, 98)	64 (41, 114)		0.198		
Alanine transaminase (U/L) (n = 152)	56 (36, 94)	64 (36, 125)		0.289		
Alkaline phosphatase (U/L) (n = 139)	170 (99, 296)	185 (121, 296)		0.473		
Microbiologic findings						
Bacteremia	36 (48.0%)	41 (52.6%)	0.83 (0.44—1.58)	0.572		
Klebsiella pneumoniae infection	37 (49.3%)	47 (60.3%)	0.64 (0.34—1.22)	0.175		
Polymicrobial infection	6 (8.0%)	15 (19.2%)	0.37 (0.12, 0.99)	0.044		
Culture-negative	25 (33.3%)	10 (12.8%)	3.35 (1.50—7.96)	0.003	5.18 (1.94—15.78)	0.002
Appropriate empirical antibiotics (n = 117)[b]	46 (93.9%)	64 (94.1%)	0.95 (0.19—5.36)	0.957		

(*continued on next page*)

Table 2 (*continued*)

	LD/ND (n = 75)	ED (n = 78)	OR	*p*-value	Adjusted OR	*p*-value
Method of source control						
Pigtail catheter placement	29 (38.7%)	64 (82.1%)	0.14 (0.06–0.29)	<0.001	N/A	
Aspiration	1 (1.3%)	14 (17.9%)	0.07 (0.002–0.37)	<0.001	N/A	

[a] List of early complications: acute kidney injury (n = 36), endophthalmitis (n = 5), meningoencephalitis (n = 1 and abscess in another organ (n = 4).

[b] Only culture-positive cases with available antimicrobial susceptibility test results were included.

All continuous variables are presented as the median with the interquartile range unless specified otherwise. All categorical variables are presented as the number with the percentage. Odds ratios are presented with the 95% confidence interval.

Abbreviation: OR, odds ratio; HPB, hepatopancreaticobiliary; ICU, intensive care unit; SOFA, Sequential Organ Failure Assessment; N/A, not applicable.

Table 3 Characteristics of the ND (non-drainage) and D (drainage) groups.

	ND (n = 45)	D (n = 108)	OR	*p*-value	Adjusted OR	*p*-value
Demographics						
Age (years)	66 (57, 75)	66 (59, 72)		0.802		
Male gender	35 (77.8%)	74 (68.5%)	1.59 (0.72–3.76)	0.249		
Radiologic findings						
Symptom onset to diagnosis (days)	5 (1, 7)	4 (1, 7)		0.934		
Diameter of largest lesion (cm)	4.5 (3.8, 5.9)	7.0 (5.2, 8.1)		<0.001	0.63 (0.49–0.77)	<0.001
Number of lesions	1 (1, 2)	1 (1, 1)		0.335		
Cystic appearance	16 (35.6%)	97 (89.8%)	0.06 (0.03–0.15)	<0.001		
Presence of septation	32 (71.1%)	71 (65.7%)	1.27 (0.60–2.80)	0.519		
Presence of gas	1 (2.2%)	20 (18.5%)	0.11 (0.005–0.58)	0.008		
Presence of thrombophlebitis	10 (22.2%)	15 (13.9%)	1.77 (0.70–4.32)	0.204		
Comorbidities						
Diabetes mellitus	15 (33.3%)	33 (30.6%)	1.14 (0.53–2.39)	0.736		
Chronic kidney disease	4 (8.9%)	1 (0.9%)	9.34 (1.25–260.27)	0.026	9.56 (1.01–238.09)	0.084
Liver cirrhosis	7 (15.6%)	8 (7.4%)	2.29 (0.74–6.95)	0.123		
Benign biliary disease	6 (13.3%)	9 (8.3%)	1.70 (0.53–5.12)	0.343		
Current malignancy	6 (13.3%)	29 (26.9%)	0.43 (0.15–1.06)	0.070		
Current HPB malignancy	1 (2.2%)	25 (23.1%)	0.09 (0.004–0.43)	0.002	0.07 (0.004–0.39)	0.013
Receipt of liver transplantation	2 (4.4%)	6 (5.6%)	0.83 (0.11–3.91)	>0.999		
Charlson comorbidity index	3 (2, 5)	3 (2, 5)		0.849		
Severity of infection						
SOFA score (n = 149)	3 (1, 6)	2 (1, 6)		0.414		
Admission to ICU within the first 48 h	5 (11.1%)	20 (18.5%)	0.56 (0.17–1.52)	0.259		
Early complications	17 (37.8%)	32 (29.6%)	1.44 (0.68–3.00)	0.325		
Laboratory findings						
White blood cell count (/μL) (n = 152)	12,670 (9480, 16,450)	13,250 (10,140, 17,580)		0.548		
Erythrocyte sedimentation rate (mm/hour) (n = 128)	61 (36, 93)	89 (60, 105)		0.007		
C-reactive protein (mg/dL) (n = 151)	16.5 (10.8, 20.9)	18.5 (11.3, 25.7)		0.209		
Total bilirubin (mg/dL) (n = 152)	1.3 (0.7, 1.9)	1.2 (0.8, 2.0)		0.744		
Aspartate transaminase (U/L) (n = 152)	45 (33, 102)	61 (40, 112)		0.184		
Alanine transaminase (U/L) (n = 152)	53 (35, 92)	63 (38, 112)		0.241		

Table 3 (*continued*)

	ND (n = 45)	D (n = 108)	OR	*p*-value	Adjusted OR	*p*-value
Alkaline phosphatase (U/L) (n = 139)	164 (90, 286)	182 (121, 306)		0.198		
Microbiologic findings						
Bacteremia	22 (48.9%)	55 (50.9%)	0.92 (0.46–1.86)	0.818		
Klebsiella pneumoniae infection	20 (44.4%)	64 (59.3%)	0.55 (0.27–1.12)	0.093		
Polymicrobial infection	2 (4.4%)	19 (17.6%)	0.23 (0.03–0.86)	0.038		
Appropriate empirical antibiotics (n = 117)[a]	22 (100.0%)	88 (92.6%)	N/A	N/A		

[a] Only culture-positive cases with available antimicrobial susceptibility test results were included.
All continuous variables are presented as the median with the interquartile range unless specified otherwise. All categorical variables are presented as the number with the percentage. Odds ratios are presented with the 95% confidence interval.
Abbreviation: OR, odds ratio; HPB, hepatopancreaticobiliary; ICU, intensive care unit; SOFA, Sequential Organ Failure Assessment; N/A, not applicable.

Table 4 Differences in clinical outcomes according to drainage status.

	LD/ND (n = 75)	ED (n = 78)	Odds ratio	*p*-value
Primary outcome				
Recurrence within 90 days	2 (2.7%)	5 (6.4%)	0.42 (0.05–2.11)	0.443
Secondary outcomes				
30-day mortality	0 (0.0%)	2 (2.6%)	N/A	N/A
90-day mortality	4 (5.3%)	4 (5.1%)	1.04 (0.23–4.78)	>0.999
Late complications	5 (6.7%)	1 (1.3%)	4.92 (0.73–132.41)	0.112
Transfer to ICU later than 48h after diagnosis (n = 152)[a]	1 (1.3%)	0 (0.0%)	N/A	N/A
Total hospital stay (days) (n = 150)[b]	11 (8, 19)	14 (8, 21)		0.641
Duration of antibiotics (days) (n = 150)[b]	44 (36, 52)	46 (42, 58)		0.088
	ND (n = 45)	**D (n = 108)**	**Odds ratio**	***p*-value**
Primary outcome				
Recurrence within 90 days	2 (4.4%)	5 (4.6%)	1.0 (0.12–5.06)	>0.999
Secondary outcomes				
30-day mortality	0 (0.0%)	2 (1.9%)	N/A	N/A
90-day mortality	0 (0.0%)	8 (7.4%)	N/A	N/A
Late complications	4 (8.9%)	2 (1.9%)	4.94 (0.87–41.17)	0.062
Transfer to ICU later than 48h after diagnosis (n = 152)[a]	1 (2.2%)	0 (0.0%)	N/A	N/A
Total hospital stay (days) (n = 150)[b]	10 (7, 14)	15 (9, 23)		0.004
Duration of antibiotics (days) (n = 150)[b]	42 (34, 51)	46 (42, 57)		0.077

[a] One patient without information on the time of transfer to the ICU was excluded.
[b] Patients who were transferred to other hospitals for the completion of antibiotic treatment and did not report the date of treatment completion or the date of discharge were excluded.
Numeric variables are presented as the median (interquartile range). Categorical variables are presented as the number of cases and the percentage. Odds ratios are presented with the 95% confidence interval.
Abbreviation: SD, standard deviation; HPB, hepatopancreaticobiliary; ICU, intensive care unit; SOFA, Sequential Organ Failure Assessment; N/A, not applicable.

guidance and follow-up, is not only subject to inter-reader variability but also is not directly comparable with CT images. In some cases, the interventional radiologists' observations were discordant with those of the diagnostic radiologists, leaving several indeterminate lesions undrained. This was further complicated by the lack of a standardized definition of liver abscess liquefaction. Second, considerable inter-practitioner variability among interventional radiologists, i.e., different thresholds of proceeding to drainage given the same situation, might have existed. Third, although we tried to exclude as many causes other than poor liquefaction for not undergoing drainage as possible, ultrasonographic appearance was not always the only determinant of the procedure. For instance, in some patients who were critically ill with indeterminate abscesses, a drainage procedure was successfully attempted. Finally, the incidence of primary outcome was low, raising the possibility of actual difference according to drainage status undetected. However, the very fact that recurrence is infrequent implies that the abovementioned uncorrected confounders are not as significant.

Table 5 Factors associated with abscess recurrence by 90 days after diagnosis.

	Recurrence (n = 7)	No recurrence (n = 146)	Odds ratio	*p*-value	Hazard ratio	*p*-value
Demographics						
Age (years)	68 (61, 71)	66 (57, 74)		0.730		
Male gender	5 (71.4%)	104 (71.2%)	0.97 (0.19–7.77)	>0.999		
Radiologic findings						
Diameter of largest lesion (cm)	7.2 (5.5, 7.6)	5.9 (4.5, 7.8)		0.541		
Number of lesions	1 (1, 6)	1 (1, 2)		0.615		
Presence of gas	2 (28.6%)	19 (13.0%)	2.76 (0.34–14.48)	0.246		
Presence of thrombophlebitis	0 (0.0%)	25 (17.1%)	N/A	N/A		
Comorbidities						
Diabetes mellitus	3 (42.9%)	45 (30.8%)	1.70 (0.30–8.43)	0.503		
Chronic kidney disease	0 (0.0%)	5 (3.4%)	N/A	N/A		
Liver cirrhosis	2 (28.6%)	13 (8.9%)	4.18 (0.50–22.70)	0.141		
Benign biliary disease	1 (14.3%)	14 (9.6%)	1.73 (0.06–11.67)	0.522		
Current malignancy	5 (71.5%)	30 (20.5%)	9.10 (1.78–73.47)	0.007		
Current HPB malignancy	4 (57.1%)	22 (15.1%)	7.28 (1.43–41.93)	0.016	14.77 (1.75–124.66)	0.013
Receipt of liver transplantation	0 (0.0%)	8 (5.5%)	N/A	N/A		
Charlson comorbidity index	6 (4, 9)	3 (2, 5)		0.019	1.28 (0.96–1.71)	0.098
Severity of infection						
SOFA score (n = 149)	2 (2, 6)	3 (1, 6)		0.878		
Admission to ICU within the first 48 h after diagnosis	1 (14.3%)	24 (16.4%)	0.94 (0.04–6.09)	>0.999		
Early complications	2 (28.6%)	47 (32.2%)	0.88 (0.11–4.44)	>0.999		
Laboratory findings						
White blood cell count (/μL) (n = 152)	10,240 (7505, 15,130)	13,600 (9900, 17,940)		0.329		
Erythrocyte sedimentation rate (mm/hour) (n = 128)	98 (92, 105)	77 (50, 102)		0.098	1.04 (1.00–1.08)	0.059
C-reactive protein (mg/dL) (n = 151)	15.8 (11.1, 20.4)	17.7 (11.2, 25.7)		0.418		
Total bilirubin (mg/dL) (n = 152)	2.1 (0.8, 4.2)	1.2 (0.8, 1.9)		0.468		
Aspartate transaminase (U/L) (n = 152)	64 (43, 81)	58 (36, 111)		0.990		
Alanine transaminase (U/L) (n = 152)	44 (26, 58)	62 (36, 109)		0.225		
Alkaline phosphatase (U/L) (n = 139)	187 (88, 572)	181 (110, 292)		0.583		
Microbiologic findings						
Bacteremia	3 (42.9%)	74 (50.7%)	0.74 (0.13–3.66)	0.719		
Klebsiella pneumoniae infection	3 (42.9%)	81 (55.5%)	0.61 (0.11–3.02)	0.701		
Polymicrobial infection	1 (14.3%)	20 (13.7%)	1.16 (0.04–7.62)	>0.999		
Culture-negative	3 (42.9%)	32 (21.9%)	2.68 (0.47–13.46)	0.197		
Appropriate empirical antibiotics (n = 117)[a]	4 (80.0%)	106 (94.6%)	0.21 (0.02–6.50)	0.270		

Table 5 (*continued*)

	Recurrence (n = 7)	No recurrence (n = 146)	Odds ratio	*p*-value	Hazard ratio	*p*-value
Source control						
Pigtail catheter placement	3 (42.9%)	90 (61.6%)	0.47 (0.08—2.34)	0.434		
Aspiration	2 (28.6%)	13 (8.9%)	4.18 (0.50—22.70)	0.141		
Late drainage + non-drainage	2 (28.6%)	73 (50.0%)	0.42 (0.05—2.11)	0.443		
Non-drainage	2 (28.6%)	43 (29.5%)	1.00 (0.12—5.06)	>0.999		

[a] Only culture-positive cases with available antimicrobial susceptibility test results were included.
Numeric variables are presented as the median (interquartile range) unless specified otherwise. Categorical variables are presented as the number of cases and the percentage. Odds ratios and hazard ratios are presented with the 95% confidence interval.
Abbreviation: HPB: hepatopancreaticobiliary; ICU: intensive care unit; SOFA: Sequential Organ Failure Assessment; N/A, not applicable.
[b] Statistics calculated with the time-dependent variable.
*Calculated from the model with variable "Late drainage + non-drainage".
**Calculated from the model with variable "Non-drainage".

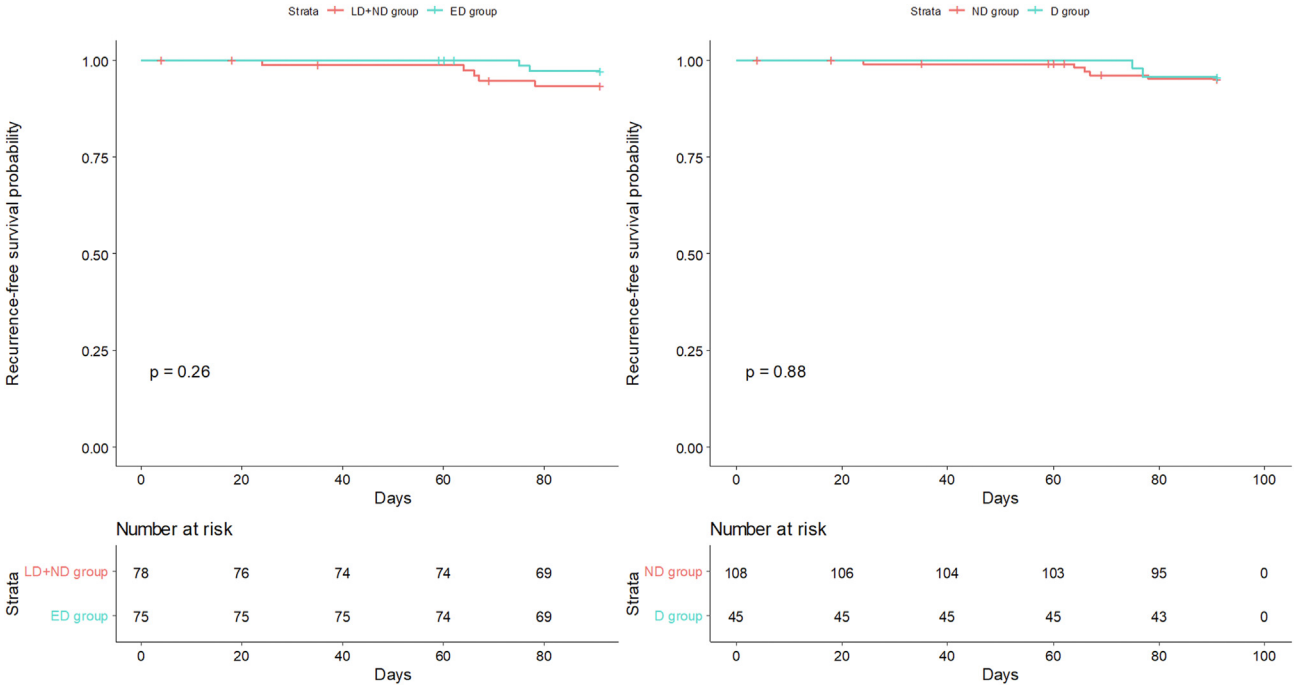

Figure 2. Kaplan—Meier curve for recurrence-free survival.

In conclusion, we identified the factors that were associated with LD/ND or ND, However, neither of these were significantly associated with unfavorable outcomes.

Declaration of competing interest

We have no financial relationships to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmii.2022.07.010.