Diagnostic performance of multidetector CT for acute cholangitis: evaluation of a CT scoring method

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Objective: The aim of this study was to retrospectively assess the diagnostic performance of multidetector CT (MDCT) for the diagnosis of acute cholangitis using a new scoring method.

Methods: Of 80 patients with suspected biliary disease who underwent biphasic CT and endoscopic retrograde cholangiography, 39 were diagnosed as having acute cholangitis (Group 1) and 41 patients were classified as suspected biliary disease (Group 2). 100 age-matched patients without evidence of biliary disease were selected randomly as a control group (Group 3). Each patient's axial scan was scored by two independent radiologists for the extent of transient hepatic attenuation difference, the presence of biliary dilatation and identification of a biliary obstructive lesion. The difference in the scores among the three groups was evaluated and the optimal cut-off score for the diagnosis of acute cholangitis was determined. Interobserver agreement was also evaluated.

Results: The total scores (mean $\pm$ standard deviation) for Groups 1, 2 and 3 were 7.0 ± 2.0 , 4.4 ± 2.4 and 0.9 ± 1.2 , respectively, for Reviewer 1 and 7.2 ± 2.7 and 0.7 ± 1.1 , respectively, for Reviewer 2. Significant differences were found for the subscores and the total scores among the three groups ($p < 0.001$). Using a cut-off score of ≥ 5 , the sensitivity and specificity for diagnosing acute cholangitis were 84.6% and 83.7%, respectively, for Reviewer 1 and 89.7% and 83.7%, respectively, for Reviewer 2. Agreement for the subscores between readers was good to excellent ($\kappa = 0.74$ – 0.86).

Conclusion: Based on dynamic MDCT and the described CT scoring method, the diagnosis of acute cholangitis can be made with high sensitivity and specificity.

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Acute cholangitis is a potentially life-threatening condition that occurs as a result of acute inflammation and infection in an obstructed bile duct [1, 2]. Because both biliary obstruction and bile infection are required for the development of acute cholangitis, these factors are essential to the pathophysiology and diagnosis of this entity [3, 4].

Traditionally, the clinical manifestations, including Charcot's triad (the presence of fever and/or chills, abdominal pain and jaundice), have been regarded as important factors for making the diagnosis of acute cholangitis [1–4]. However, the frequency of Charcot's triad varies and has been reported to be present in 15.4–72.0% of patients [4]. Diagnostic criteria were established by the International Consensus Meeting, held in Tokyo in 2006 [4]. The diagnostic criteria for a definite diagnosis of acute cholangitis include the presence of Charcot's triad. In addition, laboratory data and imaging findings are needed to support the clinical diagnosis in patients without all of the components of Charcot's triad. In this situation, laboratory data provide information about infection/inflammation and imaging is used to determine the degree and level of the biliary obstruction and

to identify the obstructing lesion in the bile duct. In previous studies, multidetector CT (MDCT) has been shown to be an accurate imaging tool for the detection of biliary obstruction [5, 6].

Transient hepatic attenuation differences (THADs), which appear as focal or diffuse hyperdense areas during the hepatic arterial phase on the CT, have been reported to be common in patients with acute cholangitis [7–9]. The incidence of THADs in patients with acute cholangitis has ranged from 71% to 98%. In addition, one study reported that the THADs observed in patients with suspected biliary disease correlated with the clinical parameters of inflammation [9]. Therefore, we developed a new scoring method for the diagnosis of acute cholangitis using dynamic contrast-enhanced MDCT. This method considers two important diagnostic factors: biliary obstruction and biliary inflammation. The purpose of this study was to retrospectively assess the diagnostic performance of MDCT for the diagnosis of acute cholangitis using a new scoring system.

Methods and materials

The institutional review board approved this retrospective study and the need for patient informed consent was waived.

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Table 1. Final diagnosis of patients

Final diagnosis of study patients (n=80)	Patient (no.)	Final diagnosis of control patients (n=100)	Patient (no.)
Biliary stones (n=44)		Pancreatic disease (n=28)	
Extrahepatic stones	43 (24)	Acute pancreatitis	22
Both extrahepatic and intrahepatic stones	1 (1)	Chronic pancreatitis	2
Biliary obstruction by tumours (n=18)		Pancreatic cystic lesion	3
Bile duct cancer	8 (2)	Pancreatic cancer	1
Pancreatic cancer	5 (2)	Liver disease (n=10)	
Ampulla of Vater cancer	3 (1)	Acute hepatitis A	1
Ampullary adenoma	1 (0)	Chronic liver disease including cirrhosis	7
Biliary IPMN	1 (1)	Hepatic haemangioma	2
Biliary stent malfunction by (n=2)		Gallbladder disease (n=24)	
Tumour in-growth (bile duct cancer)	2 (2)	Gallstones	7
Miscellaneous conditions (n=16)		Polyps	2
Choledochocoele	1 (0)	Adenomyomatosis	1
B-Obx by pancreatitis	2 (1)	Acute cholecystitis	9
Papillitis	1 (0)	Chronic cholecystitis	5
Suspected sphincter of Oddi dysfunction	1 (0)	Gastric ulcer (n=1)	1
B-Obx by periampullary diverticulum	1 (1)	Normal (n=37)	37
Suspected passed stone	3 (2)		
Benign stricture of bile duct	7 (2)		

B-Obx, biliary obstruction; IPMN, intraductal papillary mucinous neoplasm; no., number.
Values in parentheses are the number of patients with acute cholangitis.

Patient selection

A computerised search of the database at Cheonan Hospital revealed 97 patients had undergone biphasic CT examinations of the upper abdomen and endoscopic retrograde cholangiography (ERC) or percutaneous trans-hepatic biliary drainage (PTBD) between January 2008 and December 2008. 17 patients were excluded from the study owing to 1 of the following: (a) a history of previous hepatic resection ($n=4$); (b) the endoscopic retrograde cholangiography failed ($n=2$); (c) patients underwent endoscopic transpapillary gallbladder drainage owing to cholecystitis without evidence of bile duct disease ($n=2$); or (d) patients underwent CT examination more than 3 days after the admission ($n=9$). Finally, the study population included 80 patients that consisted of 52 males and 28 females (age range, 31–97 years; mean, 67 ± 15 years; median, 71 years). The mean time between the CT examination and the ERC or PTBD was 1 day (range, 0–3 days). The final diagnoses of the patients are listed in Table 1. Among the 18 cases with biliary obstruction caused by tumours, 10 were diagnosed via surgery or biopsy, 5 were diagnosed based on cytological results and imaging findings, 2 were diagnosed using imaging findings and clinical follow-up and 1 intraductal papillary mucinous neoplasm (IPMN) was diagnosed by visualisation of mucin during an endoscopy. Among 16

patients with miscellaneous causes, 3 were clinically suspected of spontaneous passage of a biliary stone based on the ERC findings; a laceration was observed at the swollen duodenal papilla without evidence of a stone in the bile duct. Seven patients were clinically diagnosed as having a benign biliary stricture on the basis of gradual narrowing of the extrahepatic bile duct without an obstructive mass observed on the CT and ERC. Two of these patients who had previously undergone choledochojunostomy had anastomotic strictures. In addition, two patients with benign strictures had no malignant cells on brush cytology and all seven patients had no remarkable changes on the imaging findings during a follow-up period of more than 6 months after the initial study (mean, 8.5 months; range, 6–12 months).

Based on the diagnostic criteria for acute cholangitis, according to the Tokyo guidelines [4] (Table 2), we selected 39 patients with acute cholangitis (Group 1); 10 patients had all of the components of Charcot's triad and 29 patients without all the components of Charcot's triad had laboratory results indicating inflammation and abnormal liver function, with imaging findings suggestive of biliary obstruction. The other patients that did not meet these criteria were classified as the suspected biliary disease group (Group 2; $n=41$). The clinical findings that led Group 2 patients to undergo ERC were as follows: a biliary abnormality on an imaging study

Table 2. Diagnostic criteria for acute cholangitis (Tokyo guidelines [4])

A. Clinical context and clinical manifestations	1. History of biliary disease
	2. Fever and/or chills
	3. Jaundice
	4. Abdominal pain (right upper quadrant or upper abdominal)
B. Laboratory data	5. Evidence of inflammatory response ^a
	6. Abnormal liver function tests ^b
C. Imaging findings	7. Biliary dilatation, or evidence of an aetiology
D. Definite diagnosis	(1) Charcot's triad (2+3+4)
	(2) Two or more items in A plus both items in B and item C

^aAbnormal white blood cell count, increase of serum C-reactive protein level and other changes indicating inflammation.

^bIncreased serum alkaline phosphatase, gamma-glutamyltransferase, aspartate aminotransferase, alanine aminotransferase levels.

Table 3. Summary of new scoring system for diagnosis of acute cholangitis

Three factors	Score	Definition
Extent of THAD	0	No involved segment
	1	1 or 2 involved segments
	2	3 or 4 involved segments
	3	5 or 6 involved segments
	4	7 or 8 involved segments
Biliary dilatation	0	Normal diameter
	1	Borderline dilatation
	2	Definite dilatation
Obstructive lesion	0	No obstructing lesion
	1	Suspicious obstructing lesion
	2	Definite obstructing lesion

THAD, transient hepatic attenuation difference.

($n=8$), laboratory test abnormalities ($n=4$) and abnormalities in both the imaging studies and laboratory tests ($n=29$). Therefore, Group 2 patients included those who had clinically suspected biliary disease and proved to have no evidence of infection in the biliary tract.

In addition, we randomly selected 100 control patients (Group 3) that underwent a biphasic CT examination during the study period without clinical evidence of biliary disease. The control patients consisted of 71 males and 29 females that were age-matched with the study patients (age range, 30–89 years; mean, 65 ± 14 years; median, 69 years). The final diagnoses of the control subjects are summarised in Table 1.

Among the 180 patients, 20 patients had previously undergone a cholecystectomy. The medical records of the patients were reviewed to collect clinical and laboratory data. The results of the laboratory tests and clinical symptoms on the date of hospital admission were used for the diagnosis of acute cholangitis. The mean time between the admission and the CT examination was 1 day (mean, 0.7 ± 0.7 days; range, 0–3 days).

CT technique

All patients underwent MDCT with one of two scanners [LightSpeed Ultra (8-channel)/LightSpeed VCT (64-channel); GE Healthcare, Milwaukee, WI] with the following parameters: detector collimation 0.625–1.250 mm, table pitch 1:0.984–1.350, matrix 512×512 and reconstruction intervals 3.75–5.00 mm. A biphasic CT examination of the upper abdomen was designed for the evaluation of the pancreas and biliary tree in patients with suspected disorders of these organs. Unenhanced scans were obtained with a 5.0 mm slice thickness and interval. Contrast-enhanced scans were performed with two-phase dynamic scanning after injection of 100 ml of non-ionic contrast material (Iomeron 350, Bracco, Milan, Italy; Omnipaque 350, Nycomed/GtE Healthcare) at a rate of 3.8 ml s^{-1} . This was followed by a 15 ml saline flush administered

at a rate of 1.5 ml s^{-1} . A bolus-tracking technique (SmartPrep; GE Healthcare) was used to determine the scan delay time. The late arterial phase scanning was initiated 18 s after reaching a preferred attenuation threshold (100 HU) from a region of interest placed at the lumen of the abdominal aorta; the reconstruction thickness and interval were 3.75 mm. Portal venous phase images were obtained 60 s after the initiation of the contrast material injection; the reconstruction thickness and interval were 5 mm.

Image analysis

The axial CT scans were reviewed independently on a picture archiving and communication system by two attending abdominal radiologists who had 3 years and 12 years (Reviewer 1 and Reviewer 2, respectively) of experience. The reviewers were aware of the study design but had no knowledge of the final diagnosis and clinical history of the patients. The axial CT scans of the study patients were randomly mixed with those of control subjects by one radiologist who did not participate in the review process.

We developed a new scoring method for the diagnosis of acute cholangitis that consisted of three factors: the presence of a THAD, biliary dilatation and an obstructing lesion; these factors were assessed by the reviewers (Table 3).

Using the method introduced by Kim et al [9], the extent of the THAD was scored by counting the liver segments involved (Couinaud's numbering system, segments I–VIII) regardless of the individual morphology on the following five-point scale (Table 3). The extent of the THAD was evaluated on late arterial phase images with the soft-tissue setting of both a narrow window width and window level (200 HU and 120 HU, respectively).

The diameter of the biliary tree was scored on a three-point scale (Table 3). First, the reviewers scrolled up and down to determine the long axis of the extrahepatic duct. Then, the diameter of the extrahepatic duct was measured as perpendicular to the long axis of the extrahepatic duct at the level of the common hepatic duct. The reviewers measured the diameters above the confluence of the cystic duct three times and then the mean of these values was finally used. Normal or abnormal diameters of the extrahepatic duct according to age or cholecystectomy are summarised in Table 4 [10]. When dilatation of the intrahepatic duct was observed, cases with a measured ductal diameter >3 mm were scored as 2, and cases with the diameter measuring <3 mm were scored as 1 [10]. In cases with dilatation of both intrahepatic and extrahepatic ducts, the diameter of the extrahepatic duct was used as a score for the biliary dilatation.

Table 4. Assessment for diameter of extrahepatic bile duct (mm)

Biliary dilatation	<50 years	51–60 years	61–70 years	>70 years	Any age with cholecystectomy
Normal diameter	≤ 5.9	≤ 6.9	≤ 7.9	≤ 8.9	≤ 7.9
Borderline dilatation	6–7.9	7–8.9	8–9.9	9–10.9	8–9.9
Definite dilatation	≥ 8	≥ 9	≥ 10	≥ 11	≥ 10

Finally, the reviewers rated the likelihood of the presence of a biliary obstructive lesion on the in three-point scale described in Table 3. The presence of an obstructive lesion in the bile duct was defined as identification of a possible lesion that caused dilatation of the biliary tree, such as a stone, a mass or bile duct narrowing on CT; it was not simply recorded as the presence of biliary dilatation.

In patients who underwent biliary stent placement ($n=2$) or choledochojunostomy ($n=2$), the ductal diameter was measured only at the intrahepatic duct and the presence of an obstructive lesion was identified when a soft-tissue density lesion or a stone was seen within the stent lumen or around the anastomotic site.

Statistical analysis

For the identification of a biliary obstructive lesion, the accuracies of both reviewers for the detection of an obstructive lesion were calculated. Based on the final diagnosis, the 180 patients were divided into 2 groups according to whether they had an identifiable obstructing lesion; 76 patients had an identifiable obstructing lesion and 104 patients did not (4 patients with a diagnosis of a passed biliary stone and sphincter of Oddi dysfunction were classified as patients without an identifiable lesion on imaging). The biliary obstructive lesion was considered present with a score of 1 or 2 and absent with a score of 0.

For each patient in the three groups, subscores of the three categories (THAD, biliary dilatation and biliary obstructive lesion) were added together to generate a total score. One-way analysis of variance was performed to determine significant differences in the mean scores of the three factors and the sum of these factors among the three groups. In addition, the *post hoc* Bonferroni test was used to determine significant differences between all possible pairs of these scores among the three groups. Receiver operating characteristic (ROC) analysis was performed to determine the optimal cut-off score, balancing sensitivity and specificity for the diagnosis of acute cholangitis and to define the optimal cut-off score differentiating Group 1 from Group 2. Interobserver agreement for each subscore of the three categories was

assessed with kappa statistics, as described by Landis and Koch [11], and interpreted as follows: <0.20 slight agreement; 0.21–0.40 fair agreement; 0.41–0.60 moderate agreement; 0.61–0.80 good agreement; and >0.80 excellent agreement. p -values <0.05 were considered statistically significant. In the Bonferroni multiple comparison test, p -values <0.017 were considered statistically significant. Data analyses were performed using SPSS for Windows (SPSS Inc., Chicago, IL).

Results

CT detection of biliary obstructive lesion

For the detection of a biliary obstructive lesion, Reviewer 1 had 61 true-positive, 102 true-negative, 15 false-negative and 2 false-positive interpretations. The detection performance for Reviewer 1 had a sensitivity of 80.2%, a specificity of 98.1%, a positive predictive value of 96.8% and a negative predictive value of 87.2%. Reviewer 2 had 64 true-positive, 101 true-negative, 12 false-negative and 3 false-positive interpretations. The detection performance for Reviewer 2 had a sensitivity of 84.2%, a specificity of 97.1%, a positive predictive value of 95.5% and a negative predictive value of 89.4%. The overall detection accuracy was 90.1% for Reviewer 1 and 91.7% for Reviewer 2.

11 cases with an obstructive cause were missed by the 2 reviewers. The obstructive lesions of the 11 cases were as follows: extrahepatic duct stones ($n=5$), benign stricture of the bile duct ($n=2$), choledochocoele ($n=1$), bile duct cancer ($n=1$), papillitis ($n=1$) and biliary obstruction by perampullary diverticulum ($n=1$).

CT diagnosis of acute cholangitis

The average and standard deviation of the subscores for the three factors and the total scores of the three groups are listed in Table 5. The mean total scores for Group 1, Group 2 and Group 3 were 7.0, 4.4 and 0.9, respectively, for Reviewer 1 and were 7.2, 4.3 and 0.7, respectively, for Reviewer 2 (Table 5).

Significant differences were found for the subscores of the 3 factors (Reviewer 1, $F=66.13$ for THAD,

Table 5. Subscores for each factor and total scores in three groups

Groups		Reviewer 1	Reviewer 2
Group 1 (Acute cholangitis)	THAD	3.5 ± 1.3	3.5 ± 1.1
	B-D	1.8 ± 0.6 ^a	1.9 ± 0.5
	B-Obx	1.7 ± 0.6	1.8 ± 0.5
	Total	7.0 ± 2.0	7.2 ± 1.8
Group 2 (Suspected biliary disease)	THAD	1.9 ± 1.6	1.7 ± 1.6
	B-D	1.5 ± 0.8 ^a	1.5 ± 0.8
	B-Obx	1.0 ± 0.9	1.2 ± 0.9
	Total	4.4 ± 2.4	4.3 ± 2.7
Group 3 (Control subjects)	THAD	0.7 ± 1.1	0.5 ± 0.9
	B-D	0.2 ± 0.5	0.1 ± 0.5
	B-Obx	0.0 ± 0.1	0.0 ± 0.1
	Total	0.9 ± 1.2	0.7 ± 1.1

B-D, presence of biliary dilatation; B-Obx, identification of a biliary obstructive cause; THAD, transient hepatic attenuation difference. Values consist of mean ± standard deviation.

^aAll pairs of the subscores and total scores for both reviewers were significantly different with the exception of the comparison of biliary dilatation between Group 1 and Group 2 by Reviewer 1.

Table 6. Optimal cut-off score for diagnosis of acute cholangitis according to reviewers

Cut-off score	Reviewer 1		Reviewer 2	
	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
G1 vs G2+3				
TS $\geq$ 4	89.7	76.6	94.9	78.0
TS $\geq$ 5	84.6	83.7	89.7	83.7
TS $\geq$ 6	82.1	87.2	82.1	87.9
TS $\geq$ 7	79.5	93.6	82.1	92.9
G1 vs G2				
TS $\geq$ 4	89.7	34.1	94.4	36.6
TS $\geq$ 5	84.6	46.3	89.7	48.8
TS $\geq$ 6	82.1	56.1	82.1	61.0
TS $\geq$ 7	79.5	78.0	82.1	75.6

G, group; TS, total score.

$F=140.14$ for biliary dilatation and $F=170.21$ for obstructive lesion; Reviewer 2, $F=99.86$ for THAD, $F=161.00$ for biliary dilatation and $F=197.33$ for obstructive lesion) and total scores ($F=185.75$ for Reviewer 1 and $F=210.45$ for Reviewer 2) among the 3 groups for Reviewer 1 and Reviewer 2 ($p<0.001$). In addition, paired analysis of the groups for the three subscores and the total scores showed significant differences between all possible pairs of the subscores and total scores for Reviewer 1 and Reviewer 2 ($p<0.017$), with the exception of the comparison of biliary dilatation between Group 1 and Group 2 by Reviewer 1 ($p=0.157$) (Table 5).

The sensitivities and specificities according to the cut-off value for the total score are listed in Table 6. The cut-off score that optimised the sensitivity and specificity for the diagnosis of acute cholangitis was 5, resulting in a sensitivity of 84.6% and a specificity of 83.7% for Reviewer 1 and a sensitivity of 89.7% and a specificity of 83.7% for Reviewer 2 (Table 6) (Figures 1 and 2). Among Group 1 patients, six were scored <5 by Reviewer 1 and four were scored <5 by Reviewer 2 (Figure 3). Four cases that scored <5 by both reviewers had the following final diagnoses: a passed biliary stone ($n=1$), extrahepatic duct stone ($n=1$), cholangiocarcinoma ($n=1$) and biliary obstruction caused by perampullary diverticulum ($n=1$). In Group 2, the CT scans were scored as ≥ 5 in 20 patients by Reviewer 1 and in 19 patients by Reviewer 2

(Figure 4). In Group 3, one case was scored as ≥ 5 or higher by Reviewer 1 and two cases by Reviewer 2. ROC analysis resulted in a cut-off score of 7 as optimal for differentiation between Group 1 and Group 2; with a cut-off value of 7, our scoring method had a sensitivity of 79.5% and a specificity of 78.0% for Reviewer 1 and a sensitivity of 82.1% and a specificity of 75.6% for Reviewer 2 (Table 6).

Interobserver agreement for the extent of THAD was good ($\kappa=0.74$). The agreement was excellent for the detection of biliary dilatation ($\kappa=0.84$) and for the detection of a biliary obstructive lesion ($\kappa=0.86$).

Discussion

The first radiological evaluation for acute cholangitis was performed using CT by Balthazar and colleagues [12]. They reported that the clinical diagnosis of acute cholangitis could be confirmed by demonstration of biliary obstruction using CT examination in 87% of patients. Subsequently, with advances in hardware and software technology, CT has been regarded as a reliable imaging modality with good diagnostic accuracy for biliary obstruction [5, 6, 13–16]. In this study, we achieved a sensitivity of 80–84%, a specificity of 97–98% and an accuracy of 90–92% in the CT detection of biliary

Figure 1. 67-year-old male with common bile duct stones (Group 1). (a,b) Arterial phase CT scans (window width, 200 HU; window level, 120 HU) show diffuse mottled enhancement on the entire liver parenchyma. Also note dilatation of the intrahepatic bile ducts (arrows on b). (c) Unenhanced CT scan shows calcified stones in the distal common bile duct (arrow) and gallbladder (small arrow). On the image analysis, subscores for the extent of transient hepatic attenuation difference, presence of biliary dilatation and identification of an obstructive lesion were 4, 2 and 2, respectively for both reviewers. Diagnosis of acute cholangitis was made on the basis of the presence of abdominal pain, fever and jaundice (Charcot's triad).

Figure 2. 77-year-old female with cholangiocarcinoma (Group 2). (a,b) Arterial phase CT scans show biliary dilatation (arrows on a) and subtle enhancement in the liver segment 3 (arrows on b). (c) Arterial phase CT scan shows a polypoid mass (arrows) within the distal portion of the common bile duct. Pathologically, adenocarcinoma was confirmed. On the image analysis, subscores for the extent of transient hepatic attenuation difference, presence of biliary dilatation and identification of an obstructive lesion were 1, 2 and 1 for Reviewer 1 and 1, 2 and 2 for Reviewer 2, respectively. The patient was classified as belonging in Group 2 (jaundice, no abdominal pain, no fever, a bilirubin level of 9.5 mg dl^{-1} and a white blood cell count of $6,520 \mu\text{l}^{-1}$).

obstructive lesions. Undoubtedly, the recently introduced MDCT cholangiography using advanced post-processing techniques allows for a more accurate diagnosis of biliary obstruction [13–16]. Nevertheless, our results using the axial images of a MDCT showed good accuracy for the detection of biliary obstruction; the results are comparable with a previous study using both multiplanar and minimum intensity reformations [6]; however, because an aetiological diagnosis was not made in our study, an exact comparison between the two studies may be limited.

Identification of a bile infection itself by imaging modalities was thought to be impossible [4]. However, attempts to visualise a bile infection have been reported [7, 9]. THADs can frequently occur on dynamic CT scans and have been associated with various pathological conditions involving the liver [17, 18]. The development of THADs is related to hepatic arterial compensation for decreased portal flow. Arai et al [7] reported that early inhomogeneous enhancement of the liver was frequently observed in patients with acute cholangitis. They believed that hepatic arterial flow might be increased as a consequence of dilatation of the peribiliary plexus which was thought to be caused by portal inflammation.

In another study by Pradella et al [8], THADs were observed in 71% (10/14) of patients with acute cholangitis. In these studies, the THADs appeared as irregular and inhomogeneous forms with various morphological patterns. The clinical significance of THADs in patients with acute cholangitis has been reported in a previous study [9]; the extent of THADs observed in patients with suspected biliary disease was found to have a positive correlation with the white blood cell count and C-reactive protein; that is, the THADs could provide information on a biliary infection.

In this study, the scoring method included three diagnostic factors that showed significantly different scores among the three patient groups; patients with acute cholangitis had significantly higher scores compared with the other two groups. These results raise the possibility that identification of biliary infection or the diagnosis of acute cholangitis can be made by the use of dynamic CT scanning. In addition, there were significant differences in the comparison of possible pairs of subscores among the three groups, with the exception of biliary dilatation between Groups 1 and 2, for one reviewer. This one exception may be related to the fact that Group 2 consisted of patients with suspected biliary

Figure 3. 84-year-old female with common bile duct stones (Group 1). (a,b) Arterial phase CT scans show focal enhancement of the liver around the gallbladder fossa (arrows) and a gallbladder stone (small arrow on b). (c) Unenhanced CT scan shows a calcified stone in the distal common bile duct (arrow). On the image analysis, subscores for the extent of transient hepatic attenuation difference, presence of biliary dilatation and identification of an obstructive lesion were 1, 0 and 2 for Reviewer 1, and were 2, 1 and 2 for Reviewer 2, respectively. Diagnosis of acute cholangitis was made on the basis of the presence of abdominal pain, fever and jaundice (Charcot's triad).

Figure 4. 73-year-old female with cholangiocarcinoma (Group 2). (a,b) Arterial phase CT scans show polymorphous enhancement in the both lobes of the liver (large arrows) and biliary dilatation (small arrows on a). (c) Arterial phase CT scan shows an enhancing mass (arrow) in the distal portion of the common bile duct. Malignancy was diagnosed based on cytological results and imaging findings. On the image analysis, subscores for the extent of transient hepatic attenuation difference, presence of biliary dilatation and identification of an obstructive lesion were 4, 2 and 1, respectively for both reviewers. The patient was classified as belonging in Group 2 (jaundice, abdominal pain, no fever, a bilirubin level of 28 mg dl^{-1} and a white blood cell count of $8400 \mu\text{l}^{-1}$).

disease that underwent ERC and in some patients the difference between Group 1 and Group 2 might be the presence or absence of biliary infection.

In our study, when the total score of ≥ 5 was used as a cut-off score, the sensitivities were 84.6% and 89.7% and the specificities were 83.7% and 83.7% for the 2 reviewers for the diagnosis of acute cholangitis. At a higher cut-off score of ≥ 7 , the specificity increased to 93.6% and 92.9% for Reviewer 1 and Reviewer 2, respectively, allowing the exclusion of cases without cholangitis with high scores. The vast majority of these patients, in whom a diagnosis of acute cholangitis was not made, with high scores were in Group 2 ($n=20$ scored by Reviewer 1; $n=19$ scored by Reviewer 2). In an additional evaluation with the ROC analysis between Groups 1 and 2, an optimal cut-off score for differentiating between two groups increased to ≥ 7 , resulting in sensitivities of 79.5% and 82.1% and specificities of 78.0% and 75.6% for Reviewer 1 and Reviewer 2, respectively. In our study, because patients that belonged to Group 2 had mean subscores >1.0 in the categories of biliary dilatation and obstructive causes, the extent of the THAD may be crucial for the differentiation between these two groups. Prior reports have shown that THADs can occur in cases of biliary obstruction without bile infection [8, 9, 17]. The peribiliary plexus consists of a mesh-like vascular network around the main bile ducts, acting as a main route for arteriportal shunt in cases with biliary disease. When the peribiliary plexus becomes compressed by the dilated bile ducts, a decrease in the portal flow induces hepatic arterial compensation [8, 9, 17]. However, in cases with a bile infection, the degree of arterial compensation may be increased further by the additional effects of increased blood flow resulting from the inflammatory response. Therefore, the extent of the THAD can be expected to increase when a bile infection complicates the biliary obstruction. This is supported by the results reported in a previous study [9] as well as the findings of this study (mean scores of THAD in Group 1 *vs* Group 2: 3.5 *vs* 1.9 for Reviewer 1 and 3.5 *vs* 1.7 for Reviewer 2).

On the other hand, there were 5 cases (13%) in Group 1 that were scored <5 by Reviewer 1 and there were 4 (10%) such cases for Reviewer 2. The aetiology of the low level of total scores in patients with acute cholangitis may include a lower extent of THAD, a normal range of the bile duct diameter and non-visualisation of an obstructive cause on CT. In particular, the limitations of the CT detection of an obstructive lesion can be overcome with the combined use of other imaging modalities because MRI and endoscopic ultrasonography offer an advantage over CT for the detection of small calculi, pure cholesterol stones and biliary strictures [5, 19–21].

Our study revealed that approximately 80% of cases with the clinical diagnosis of acute cholangitis could be proven with the described CT scoring system. These findings also support the potential value of the dynamic CT as a diagnostic tool in patients with acute cholangitis. In interpreting CT scans of patients with clinically suspected biliary obstruction, the radiologist can provide referring physicians with adjunctive information, not only about biliary obstruction but also about bile infection; the possibility of inflammation in the bile duct is suspected with the higher extent of THAD. However, because a variety of conditions other than biliary disease can cause THAD [9, 17, 18], imaging or clinical evidence of biliary obstruction should precede the interpretation of THADs in the diagnosis of acute cholangitis.

The limitations of this study include the following. First, a selection bias may have been introduced in the study subjects because we only included patients that underwent both a biphasic CT scan and an ERC or PTBD. Cases examined with the single phase CT scan were excluded from our study population. In addition, there is the possibility that patients with a mild degree of acute cholangitis, in whom a subsequent ERC or PTBD was not performed, were not included; this might lead to a high proportion of patients with severe cholangitis among the study subjects. However, these procedures served as the standard of reference for the detection of an obstructive lesion in many cases included in this study. Second, although we excluded patients undergoing CT

examination more than 3 days after the admission, there was a time interval between the admission and CT examination in the study subjects. Because clinical findings including laboratory data obtained on the date of admission were used, there might have been a change in the clinical findings on the date of CT examination. However, we believe that the time intervals were minimised with the mean time interval between admission and CT examination of 1 day (mean, 0.7 days) observed in this study. Third, only axial images were used in this study. The combined use of axial and coronal images might have improved accuracy for the biliary obstruction.

In conclusion, the scoring method presented here showed that patients with acute cholangitis had significantly higher scores compared with patients with suspected biliary disease in whom no clinical evidence of inflammation was found and compared with normal patients. In addition, this method was confirmed to be good to excellent with regard to the interobserver agreement. Based on dynamic MDCT and the described CT scoring system, the diagnosis of acute cholangitis can be made with high sensitivity and specificity.

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