

Diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression/T2 image fusion for the diagnosis of acute cholecystitis

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Abstract. Prompt and accurate diagnosis is critical in the treatment of acute cholecystitis. Diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression/T2 image fusion (DWIBS/T2) identifies areas with high signal intensity, corresponding to inflammation. In the present study, the records and images of patients with acute cholecystitis who underwent DWIBS/T2 between January 2013 and March 2014 were retrospectively analyzed. A total of 11 patients with acute cholecystitis were enrolled. In one patient, DWIBS/T2 identified a thickened wall and high signal intensity, with high signal intensity in the pericholecystic space that suggested localized peritonitis. Positive DWIBS/T2 results indicating acute cholecystitis were obtained in 10/11 patients, with a sensitivity of 90.9%. In addition, wall thickening and high signal intensity were absent in DWIBS/T2 images when wall thickening was not detected by computed tomography. Wall thickening and high signal intensity was attenuated when patients with acute cholecystitis were clinically treated. These data suggest that a thickened gallbladder wall and high signal intensity are indicative of acute cholecystitis and that DWIBS/T2 may be a useful technique in evaluating the severity of acute cholecystitis.

Introduction

Acute cholecystitis is characterized by inflammation of the gallbladder and typically occurs due to obstruction of the gallbladder neck or cystic duct by a gallstone (1). Gallbladder

infection may also spread to the liver or pericholecystic cavity and lead to the development of liver abscesses or peritonitis, respectively (2-4). Therefore, prompt treatment with cholecystectomy, percutaneous transhepatic gallbladder drainage or aspiration is typically recommended following diagnosis of acute cholecystitis (5-7). Accurate diagnosis is also critical for the appropriate management of acute cholecystitis (8).

Diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression (DWIBS) is based on a diffusion-weighted imaging (DWI) technique, which enables visualization of the random movement of water molecules (Brownian motion) for diagnostic imaging (9). Images are acquired with DWIBS during free breathing of the patient through the use of multiple-signal averaging, fat suppression and heavy diffusion weighting (10). In particular, a high signal intensity of DWIBS is a positive indicator of cancer and inflammation. An advantage of DWIBS over DWI is that it exhibits positive signals with strong contrast against surrounding normal tissues. However, the evaluation of positive signals to obtain anatomical information becomes difficult when signals in the surrounding tissues are suppressed (11,12). Images obtained from DWIBS are fused with their corresponding T2-weighted images using a workstation (13-15). DWIBS and T2-weighted image fusion (DWIBS/T2) enables anatomical evaluation of the positive signals obtained from DWIBS (16). Therefore, the present study retrospectively analyzed images obtained by DWIBS/T2 from patients with acute cholecystitis to determine how useful this technique is in the management of the disease.

Patients and methods

Patients. The current study was approved by the Ethics Committee of the National Hospital Organization of Shimoshizu Hospital (Yotsukaido, Japan). Consent was obtained from patients prior to abdominal ultrasonography (US), though written informed consent was waived as abdominal US is considered to be safe and non-invasive. Written informed consent was obtained from patients before

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Table I. MRI pulse sequences.

Parameter	T1-weighted image	T2-weighted image	DWI (DWIBS)
Sequences	GRE	Single-shot SE	EPI SE
TR, msec	Shortest	1,000	11,250
TE, msec	First: 2.3 (out-of-phase); second: 4.6 (in phase)	90	83
Flip angle, (°)	75	90	90
NSA	1	1	4
Slice thickness, mm	8	8	5
Slice gap	1	1	0
Fat saturation	None	None	SPAIR
Phase encoding direction	Posterior-anterior	Posterior-anterior	Posterior-anterior

TR, repetition time; TE, echo time; DWI, diffusion-weighted imaging; DWIBS, diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression/T2 image fusion; GRE, gradient echo; SE, spin echo; EPI, echo planar imaging; NSA, number of signal averages; SPAIR, spectral attenuated inversion recovery; MRI, magnetic resonance imaging.

all patients underwent magnetic resonance (MR) cholangio-pancreatography, DWIBS/T2 and computed tomography (CT) with or without contrast enhancement. The current study was not considered a clinical trial as procedures were performed as part of routine clinical practice. Therefore, written informed consent for inclusion in the study was waived. All patient records and information were anonymized prior to analysis.

The medical records of patients who were diagnosed with acute cholecystitis and underwent DWIBS/T2 between January 2013 and March 2014 were analyzed retrospectively. A total of 8 men (mean age \pm standard deviation: 69.8 ± 4.0 years) and 3 women (72.7 ± 3.1 years) were enrolled in the current study. All patients were recruited from the National Hospital Organization Shimoshizu Hospital.

Diagnostic procedure for acute cholecystitis. Patients were diagnosed with acute cholecystitis according to the Updated Tokyo Guidelines for the Management of Acute Cholecystitis (17). Acute cholecystitis was suspected in patients with upper abdominal and/or right upper quadrant pain, and elevated white blood cell count and/or C-reactive protein levels, all of which suggested inflammation of the abdominal organs. Upper abdominal and right upper quadrant pain were identified by a Murphy's sign test, a right upper quadrant mass, general pain and/or tenderness. The diagnosis of acute cholecystitis was confirmed in these patients according to characteristic features of abdominal CT and US scans with or without contrast enhancement. These features were an enlarged gallbladder, thickened gallbladder wall and pericholecystic fluid (18). Abdominal US was a reliable method of detecting Murphy's sign test, as described previously (19). Following diagnosis, DWIBS/T2 was performed. Patients were excluded from the present study if they were unable to undergo at least one of either US, CT or DWIBS/T2.

MR imaging (MRI). All MRI examinations were performed with a 1.5-Tesla scanner using Achieva 3.2.2 software (both from Philips Medical Systems B.V., Eindhoven, The

Netherlands). Patients were placed in a supine headfirst position on an extended table platform to allow for full-body scanning from the head to the lower legs. The imaging protocol of DWIBS/T2 consisted of unenhanced T1-weighted, T2-weighted, DWI and DWIBS scans. MRI pulse sequences are presented in Table I. Images obtained from DWIBS were acquired in an axial plane with a Q-body coil under free breathing conditions using an echo-planar imaging single-shot pulse sequence. DWI gradients were applied along the X, Y, and Z axes prior to and following a pre-pulse 180° inversion, which was performed to obtain fat-saturated isotropic images with DWI sensitivity using the following parameters for a single stack: *b*-value, 0 and $800 \text{ mm}^2/\text{sec}$; repetition, echo and inversion times, 6,960/79/150 msec; acquisition matrix, 176×115 ; reconstruction matrix, 256; right/left field of view, 530 mm; anterior/posterior field of view, 349 mm; feet/head field of view, 226 mm; slice thickness, 6 mm; size of the reconstructed voxel, $2.07 \times 2.08 \times 6 \text{ mm}^3$; and 4 averages. Fused images obtained from DWIBS/T2 were constructed with the Extended MR WorkSpace workstation (Philips Medical Systems B.V.). In all patients, 5 stacks (46 slices/stack) were acquired consecutively to obtain images from the head to the middle of the tibia. The total imaging time was 13.31 min. An apparent diffusion coefficient (ADC) map was produced from the recorded ADC values in order to eliminate the possibility of T2 shine-through and to differentiate malignant lesions from non-malignant causes of restricted diffusion (20).

Results

DWIBS/T2 detects clinical features of acute cholecystitis. In one patient with acute cholecystitis, a thickened gallbladder wall and high signal intensity were observed in images obtained by DWIBS/T2 (Fig. 1A). The high signal intensity in the pericholecystic space suggested localized peritonitis (Fig. 1B). These results indicate that wall thickening and high signal intensity, as detected by DWIBS/T2, are typical features of acute cholecystitis.

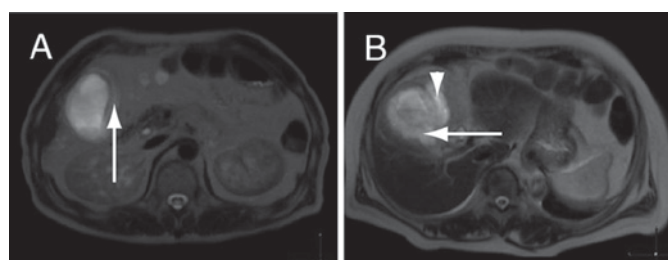


Figure 1. Results of DWIBS/T2 in acute cholecystitis patients. (A) A DWIBS/T2 image exhibiting gallbladder wall thickening (arrow) in a 70-year-old woman with acute cholecystitis. (B) A DWIBS/T2 image exhibiting high signal intensity in the pericholecystic space (arrowhead) and gallbladder wall thickening (arrow) in a 68-year-old man with acute cholecystitis. The pericholecystic space was outside the gallbladder wall. DWIBS, diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression/T2 image fusion.

Table II. Results of DWIBS/T2 in patients with acute cholecystitis.

Patient number	Wall thickening	Wall high signal intensity
1	(+)	(+)
2	(+)	(+)
3	(+)	(+)
4	(+)	(+)
5	(+)	(+)
6	(+)	(+)
7	(+)	(+)
8	(+)	(+)
9	(+)	(+)
10	(+)	(+)
11	(-)	(-)

(+), Present; (-), absent; DWIBS, diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression/T2 image fusion.

DWIBS/T2 has high sensitivity in the detection of acute cholecystitis. The sensitivity of DWIBS/T2 in the diagnosis of acute cholecystitis was determined. Images obtained by DWIBS/T2 from patients with acute cholecystitis (n=11) were evaluated to determine the extent of wall thickening and signal intensity, both positive indicators of cholecystitis. Out of the 11 patients, 10 exhibited a thickened wall and high signal intensity in the DWIBS/T2 images (Table II). Thus, positive DWIBS/T2 results were obtained in 10/11 patients (90.9%). In the remaining patient, fluid was present between the liver and gallbladder, indicating acute cholecystitis (Fig. 2A and B). The patient's DWIBS/T2 result was positive for cholecystitis (Fig. 2C), and a CT scan performed three days later identified thickening of the gallbladder wall (Fig. 2D). Disparity between results of the DWIBS/T2 and CT scans may be due to a lack of high signal intensity in DWIBS/T2 in the absence of wall thickening. Alternatively, DWIBS/T2 may infrequently yield a negative result for acute cholecystitis. Nevertheless, these results suggest that high signal intensity detected by DWIBS/T2 is

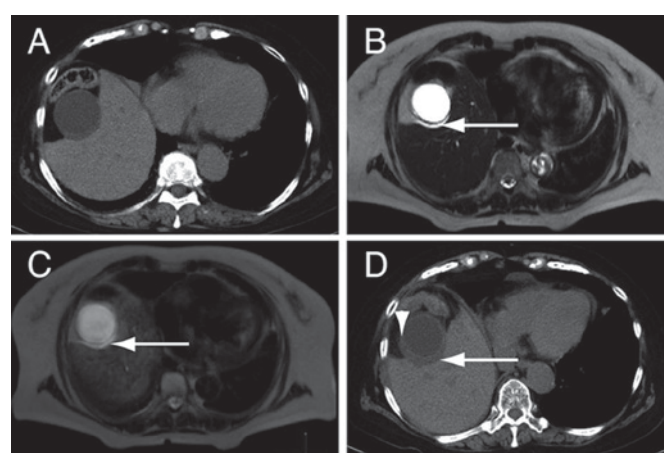


Figure 2. Negative DWIBS/T2 result in a patient with acute cholecystitis. The images represent a 72-year-old woman presenting with upper abdominal pain who was referred to the National Hospital Organization of Shimoshizu Hospital (Yotsukaido, Japan). (A) A CT image of the gallbladder wall exhibiting no indication of thickening. (B) A T2-weighted image exhibiting high signal intensity between the liver and gallbladder suggestive of fluid accumulation (arrow). (C) A DWIBS/T2 image exhibiting high signal intensity in the gallbladder wall (arrow). Based on the results from the examination, the patient was diagnosed with acute cholecystitis and treated with antibiotics. (D) A CT image exhibiting gallbladder wall thickening (arrow) and fluid accumulation (arrowhead) 3 days after initiation of antibiotic treatment. The patient subsequently underwent percutaneous transhepatic gallbladder drainage. DWIBS, diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression/T2 image fusion; CT, computer tomography.

associated with the severity of gallbladder inflammation in acute cholecystitis.

DWIBS/T2 detects improvements in acute cholecystitis. The efficacy of DWIBS/T2 in evaluating improvements in acute cholecystitis following clinical treatment was assessed. Prior to treatment, acute cholecystitis detected by abdominal US and CT examinations (Fig. 3A and B) was also evident in DWIBS/T2 images as gallbladder wall thickening coupled with high signal intensity (Fig. 3C). Following treatment with cefazolin sodium (3 g/day for 7 days; Nipro Corp., Osaka, Japan), improvements in acute cholecystitis were detected by DWIBS/T2 as reductions in gallbladder wall thickening and signal intensity (Fig. 3D).

Discussion

In acute cholecystitis, wall thickening is caused by edema of the gallbladder wall, and correlates with the severity of acute cholecystitis (21). Therefore, measurements of wall thickness may be useful in aiding the diagnosis of acute cholecystitis and in evaluating its severity (22). In particular, the detection of wall thickening and pericholecystic fluid by MRI may be a useful diagnostic tool (23). In the present study, the gallbladder wall of patients with acute cholecystitis was thickened. DWIBS/T2 identified that the thickened wall exhibited high signal intensity, which may correlate with the extent of inflammation (24). These data indicate that the detection of wall thickening by DWIBS/T2 make it an effective method in the evaluation and diagnosis of acute cholecystitis.

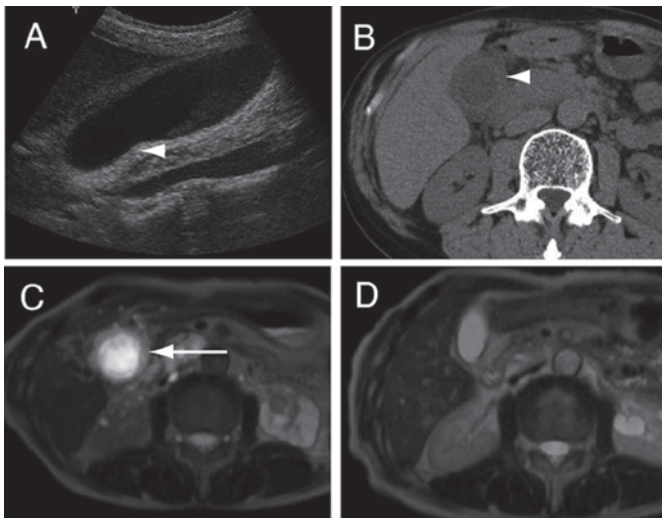


Figure 3. Follow-up examination of a patient with acute cholecystitis. The images represent a 70-year-old man presenting with upper abdominal pain who was referred to the National Hospital Organization of Shimoshizu Hospital (Yotsukaido, Japan). (A) An abdominal ultrasonography image presenting a distended gallbladder with a thickened wall (arrowhead). (B) A computed tomographic image exhibiting thickening of the gallbladder wall (arrowhead). (C) A DWIBS/T2 image exhibiting high signal intensity in the gallbladder wall (arrow). The patient was diagnosed with acute cholecystitis and underwent PTGBD. (D) A DWIBS/T2 image exhibiting marked reductions in the wall thickness and signal intensity following 5 days of PTGBD. DWIBS, diffusion-weighted whole-body magnetic resonance imaging with background body signal suppression/T2 image fusion; PTGBD, percutaneous transhepatic gallbladder drainage.

The sensitivity of abdominal US in the diagnosis of acute cholecystitis is 37.5-91% (25,26), while the sensitivity of CT is 83% (25). In the current study, the sensitivity of DWIBS/T2 in the diagnosis of acute cholecystitis was 90.9%. Similarly, previous results have indicated that DWIBS/T2 is superior to US and CT as a diagnostic tool (27,28), possibly due to the distinct contrast between high signal intensity regions and surrounding tissues detected by DWIBS/T2, which makes diagnosis more accurate. Indeed, contrast agents are considered to be useful in the diagnosis of biliary diseases (29). These results suggest that alterations in the gallbladder wall and pericholecystic fluid are useful diagnostic markers (29). DWIBS/T2 did not require the use of contrast agents, thus making it an efficient method in the diagnosis of acute cholecystitis. In the present study, DWIBS/T2 was able to detect reductions in wall thickness and signal intensity following treatment of acute cholecystitis (Fig. 3). These results suggest that DWIBS/T2 may be useful for the evaluation of acute cholecystitis severity.

The current study included limitations. Firstly, only a small number of patients with acute cholecystitis were enrolled. Secondly, the detection of gallbladder wall thickness and high signal intensity by DWIBS/T2 were not compared with other gallbladder conditions, including chronic cholecystitis and gallbladder cancer, both of which exhibit gallbladder wall thickening (30-32). As the treatments for acute cholecystitis, chronic cholecystitis and gallbladder cancer differ, distinguishing between these diseases is critical for successful treatment (1).

In conclusion, DWIBS/T2 is able to indicate the presence of acute cholecystitis through the detection of gallbladder wall thickening and high signal intensity. Furthermore, the present

results indicate that DWIBS/T2 may be useful in determining the severity of acute cholecystitis.

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