J. Tokyo Med. Univ., **66**(1) : 31-37, 2008

The usefulness of diffusion-weighted magnetic resonance imaging for diagnosis of peritoneal carcinomatosis

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Abstract

The present study was designed to verify the clinical usefulness of diffusion-weighted imaging (DWI) for diagnosis of peritoneal carcinomatosis, compared with computed tomography (CT) and conventional magnetic resonance imaging (MRI), using six patients with peritoneal carcinomatosis. The primary tumors in these six cases were pancreatic cancer in three, and colon cancer, ovarian cancer, and uterine corpus cancer in one each. Regarding three cases with large amounts of ascites, CT and T1-weighted imaging (T1WI) and T2-weighted imaging (T2WI) showed findings indicating peritoneal carcinomatosis, such as peritoneal nodules, omental nodules, and thickened bowel wall. They also showed bulky peritoneal tumor suggesting peritoneal carcinomatosis in one case with no apparent ascites. However, none of these imaging methods showed any findings indicating peritoneal carcinomatosis in one case with a small amount of ascites and another case without ascites. Disseminated lesions could be easily detected on DW images because the monochrome reverse imaging with reduced background signal intensity made the lesions stand out with good contrast. DWI clearly visualized the abnormal signals of permeated omental fat as well as the peritoneal nodules, omental nodules, and thickened bowel wall as detected by CT, T1WI, and T2WI, indicating peritoneal carcinomatosis. Many abnormal signals of peritoneal and mesenteric disseminated lesions were observed in one case in which no specific findings were obtained with conventional techniques. The mean apparent diffusion coefficient (ADC) values of the primary tumors and disseminated lesions as determined from ADC maps were $1.10\pm0.32\times10^{-3}$ mm^2/sec and $1.05\pm0.20\times10^{-3}$ mm^2/sec, respectively, with no significant difference between them. Both primary tumors and disseminated lesions showed low ADC values, suggesting malignant tumors. Although the usefulness of DWI for diagnosis of peritoneal carcinomatosis is high, there are two points requiring caution regarding interpretation. One is that disseminated lesions must be carefully distinguished from the intestinal contents, because the latter may be visualized as an area of abnormal signal intensity. The other is that metastatic lymph nodes visualized as abnormal signals must be differentiated from disseminated lesions.

Introduction

Earlier studies have shown that the diagnostic performance of computed tomography (CT) in peritoneal carcinomatosis is insufficient[1-8]. With technical improvements of imaging devices, diffusion-weighted imaging (DWI), a magnetic resonance imaging (MRI) technique that has been mainly used in the field of neuroradiology to detect acute phase cerebrovascular accidents, is now considered useful in detecting malignant tumors in the body. The present study was designed to verify the usefulness of DWI for the diagnosis of peritoneal carcinomatosis compared with CT and conventional MRI techniques.

Received July 10, 2007, Accepted September 4, 2007

Key words : peritoneal carcinomatosis, magnetic resonance imaging, diffusion-weighted images

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Materials and methods

The subjects were six cases confirmed to have peritoneal carcinomatosis by cytology of ascites or pathological examination after open abdominal surgery. They included two men and four women of 53–79 years of age. The primary tumor in these patients was pancreatic cancer in three, and colon cancer, ovarian cancer, and uterine corpus cancer in one each (Table 1). The only distant metastases detected were hepatic and bone metastasis, for each of which one case was detected.

The CT examinations were performed with a 16-multi-detector row CT (MDCT) scanner (Somatom Sensation Cardiac 16; Siemens Medical Solutions, Erlangen, Germany); the parameters were a follows: rotation time 0.5 sec; detector collimation 16×1.5 mm; helical pitch 1.0; reconstructed section thickness 5.0 and 7.0 mm. All scans were started at the top of the liver and moved to the base of the pelvic cavity in a cephalocaudal direction. Contrast enhanced CT was performed in only one case.

MR imaging was performed using a 1.5 T superconductive MR system (Avanto; Siemens Medical Solutions). The maximum gradient strength was 45 mT/m. All MR images were obtained in the axial plane with a body and spine matrix coil for the body. T1 weighted images (T1WI) were obtained under the following conditions: 173/4.5/1 (TR/TE/excitations); flip angle 90°; matrix 166×256; field of view (FOV) 300 mm; slice thickness/gap 7.0 mm/1.4 mm. T2 weighted images (T2WI) were obtained under the following condition: 4030/109/1 (TR/TE/excitations); echo train length 31; matrix 154×256; FOV 300 mm; slice thickness/gap 7.0 mm/1.4 mm. Contrast enhanced T1WI was performed in only one case. The short T1 inversion recovery (STIR) and chemical shift selective (CHESS) method were used for DWI, with b-values set at 0 and 1,000 sec/mm^2 and images shown monochrome and reversed. STIR-DW images were performed using echo planar imaging(EPI) sequence with the following parameters: 5600/180/76/8 (TR/TI/TE/excitations); echo train length 192; matrix 192×192; FOV 400 mm; slice thickness/gap 7.0 mm/1.4 mm. CHESS-DW images were performed using EPI sequence with the following parameters: 2800/78/8 (TR/TE/excitations); echo train length 51; matrix 128×128; FOV 400 mm; slice thickness/gap 7.0 mm/1.4 mm. The apparent diffusion coefficient (ADC) values of the primary tumors and disseminated lesions were determined from ADC maps. All six cases underwent MRI and five of the cases underwent CT 10 days before or after MRI. The one remaining case was excluded from the evaluation of CT because the patient did not undergo CT within two weeks of the MRI.

Table 1 clinical characteristics of 6 patients with peritoneal carcinomatosis

case	age	sex	primary tumor	other metastasis
1	53	female	pancreatic cancer	none
2	62	female	pancreatic cancer	none
3	67	male	pancreatic cancer	none
4	66	female	ovarian cancer	liver
5	70	male	colon cancer	none
6	79	female	uterine corpus cancer	bone

Results

The CT, T1W, and T2W images were examined for any abnormal findings at the peritoneum, greater omentum, mesentery, and intestinal wall. The presence/absence of ascites was evaluated on CT images taken from the abdomen to the pelvic region (Table 2). Three cases had large amounts of ascites, one had a small amount, and the remaining case had none. Case 6, which did not undergo CT, had no ascites as determined by pelvic MRI. The three cases with large amounts of ascites (cases 3, 4, and 5) also showed peritoneal nodules, omental nodules, and thickened bowel wall on CT, which indicated peritoneal carcinomatosis. Two cases showed permeated omental fat, but because this is observed in various diseases, this finding alone was not sufficient to make a definite diagnosis of peritoneal carcinomatosis. These two cases (1 and 2) thus had no findings indicating peritoneal carcinomatosis.

Table 2 CT findings in peritoneal carcinomatosis

case	ascites	peritoneum	greater omentum	bowel wall
1	minimal		permeated fat	
2	none			
3	marked		nodules	thickening
4	marked	nodules		
5	marked		permeated fat	thickening

case 5: contrast enhancement (+)

Table 3 MRI (T1WI and T2WI) findings in peritoneal carcinomatosis

case	peritoneum	greater omentum	bowel wall
1		nodules	
2			
3			thickening
4	nodules		
5		permeated fat	
6	bulky tumor		

case 6: contrast enhancement (+)

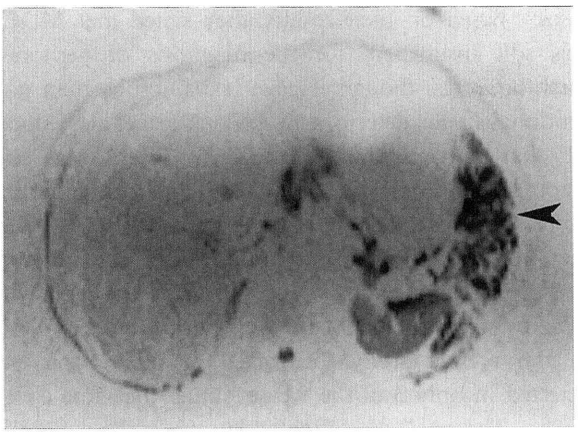

Fig. 1a DWI clearly visualizes abnormal signals lateral to the side of the greater curvature of the stomach (black arrowhead).

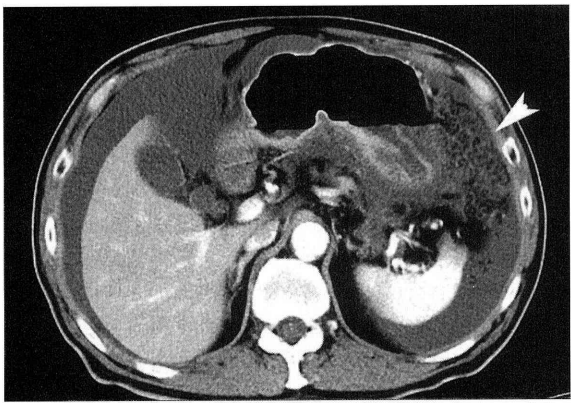

Fig. 1b Contrast enhanced CT shows permeated omental fat lateral to the side of the greater curvature of the stomach (white arrowhead); however, the CT image is insufficient for a definite diagnosis of peritoneal carcinomatosis.

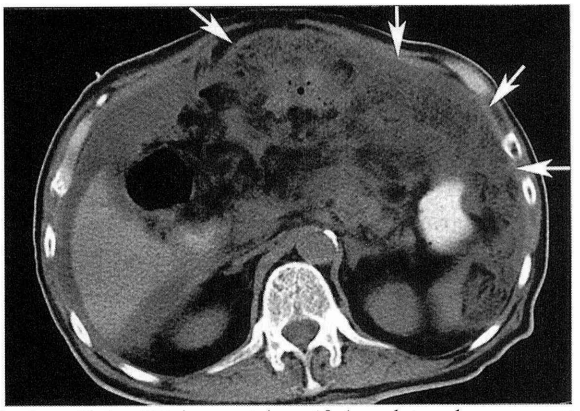

Fig. 1c Plain CT image taken 18 days later shows omental cake, which is a typical image of peritoneal carcinomatosis (arrow).

Fig. 1 Colon cancer (case 5)

Omental nodules indicating peritoneal carcinomatosis were observed in case 1, but the thickened bowel wall in case 5 was unclear on T1W and T2W images. No apparent ascites but a bulky peritoneal tumor indicating peritoneal carcinomatosis was noted in case 6 (Table 3).

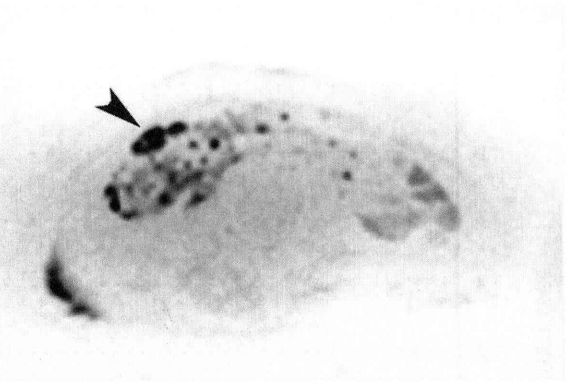

Fig. 2a DWI visualizes many abnormal signals of nodules of a few to 20 mm in diameter on the peritoneum and mesentery (black arrowhead). Both primary lesions and peritoneal nodules have low ADC values, of 1.14×10^{-3} mm^2/sec and 0.82×10^{-3} mm^2/sec, respectively.

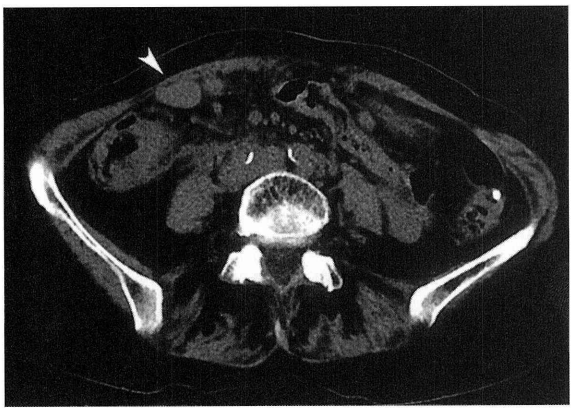

Fig. 2b Non-contrast enhanced CT visualizes mesenteric nodules detected by DWI as vascular structures, and peritoneal nodules of 20 mm in diameter as part of the intestine (white arrowhead). Examination during surgery showed a myriad of disseminated lesions on the peritoneum and mesentery.

Fig. 2 Pancreatic cancer (case 2)

Disseminated lesions were easily detected on DW images because the monochrome reverse imaging with reduced background signal intensity made the lesions stand out with good contrast. DWI clearly showed abnormal signals, not only the peritoneal nodules, omental nodules, and thickened bowel wall indicating peritoneal carcinomatosis observed by CT, T1WI, and T2WI, but also permeated omental fat (Fig. 1). Furthermore, DWI showed many abnormal signals from peritoneal and mesenteric nodules in case 2, in which no abnormal findings were observed by CT (Fig. 2). The mean ADC values of the primary tumors and disseminated lesions were as low as $1.10\pm0.32\times10^{-3}$ mm^2/sec and $1.05\pm0.20\times10^{-3}$ mm^2/sec, respectively, with no significant difference between the primary tumors and

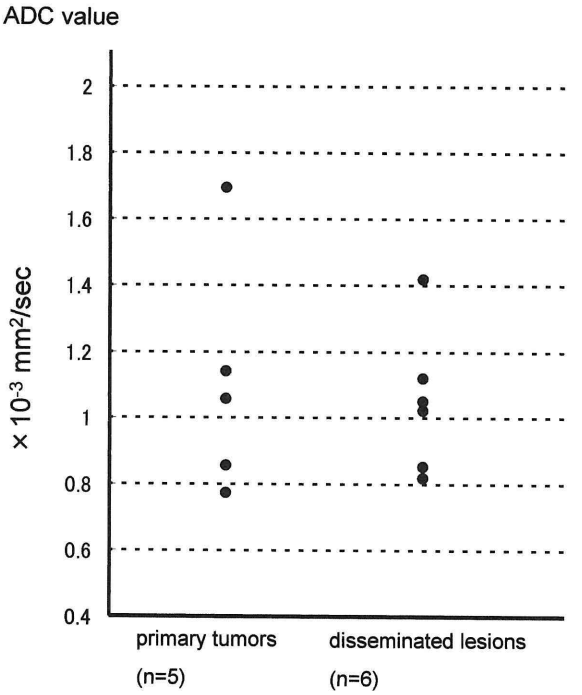

Fig. 3 ADC values of the primary tumors and disseminated lesions

disseminated lesions (Fig. 3).

Discussion

Peritoneal carcinomatosis is defined as a morbid state in which cancer in a peritoneal organ invades the serous membrane to disseminate cancer cells in the peritoneum, causing nodules. It is generally associated with ascites; peritoneal carcinomatosis without ascites is called peritoneal dissemination. The most common primary lesion is gastric cancer, followed by biliary tract cancer, pancreatic cancer, colon cancer, hepatic cancer, and ovarian cancer. It sometimes occurs by lymphogenous or hematogenous metastasis. The definitive diagnosis of peritoneal carcinomatosis is usually made by cytology of ascites or tissue diagnosis of nodules collected during surgery. Preoperative imaging diagnosis is important when the ascites cytology is negative or no ascites is present.

The findings of peritoneal carcinomatosis on CT include ascites, peritoneal thickening and enhancement, peritoneal nodules, omental cake, peritoneal tumor, and thickened bowel wall, but the percentage of correct diagnoses based on CT is not high[1–8]. Some studies have reported that the diagnosis of early peritoneal dissemination could not be made unless the condition was associated with ascites[9–11]. Shinohara et al.[12] reported that, using MDCT, T and N factors in advanced gastric cancer could be correctly determined preoperatively in a high percentage of patients; however peritoneal carcinomatosis was detected in only 6 of 15 cases. Based on their results, they stated that MDCT was still insufficient for the diagnosis of peritoneal carcinomatosis, though it gave better results than conventional single-detector row CT. Nozu et al.[13] reported that preoperative CT detected peritoneal carcinomatosis in only 1 of 9 cases, but that intraperitoneal nodules of 2–8 mm were identified in 8 of 9 cases when they were retrospectively examined in cine paging mode and a single-image display on the monitor with a wide window width of 400 HU, a low window level of 0 HU. In the present study, peritoneal carcinomatosis was detected in only 3 of the 5 cases under the same conditions. The small disseminated lesions in the remaining two cases with small or no ascites were not detected by CT.

Diagnosis of peritoneal carcinomatosis by conventional MRI was reported to require a longer examination period and have a lower diagnostic performance than CT in the upper abdominal area affected by respiration artifact[14]. Forstner et al.[15] reported that conventional MRI had a sensitivity of only 20% for the detection of disseminated lesions in the mesentery or small intestine, but had good diagnostic performance for disseminated lesions in the pelvic cavity (which is less affected by respiration artifact), particularly Schnitzler tumor. Several studies have reported that gadolinium-enhanced fat-suppressed T1W imaging has good contrast resolution and visualizes disseminated lesions more clearly than contrast enhanced CT, but has limitations in the diagnosis of small disseminated lesions[16–19]. In the present study, the performance of the non-contrast enhanced MRI was inferior to CT in the detection of epigastric disseminated lesions, though gadolinium-enhanced fat-suppressed T1W imaging could not be evaluated definitely because it was used in only one case.

With the development of MRI hardware and software in the latter half of the 1990s, DWI using EPI sequences became clinically widespread and established as useful for the diagnosis of acute phase cerebral infarction (within 1 h from onset). Although it was expected that the technique would be applied to the field of abdominal examination, it was not put to practical use because of image deterioration and reduced signal-to-noise ratio due to EPI-specific artifact. After Ichikawa et al.[20] and Yamashita et al.[21] described the usefulness of the technique in the abdominal field, Nasu et al.[22] in 2004 reported a combination of the technique with parallel imaging, and this was rapidly put to clinical use because of the reduced artifact and the ability to perform DWI at high b values. Human tissues can be roughly divided into cells and intercellular space, and the diffusion contrast of DWI mainly depends on water molecules in the intercellular space. The cells in a malignant tumor are increased in number or enlarged, narrowing the

intercellular space and restricting water molecule diffusion, which is observed as an abnormal signal[23]. Two fat-suppression methods are used for DWI : the STIR and CHESS methods. The STIR method gives even fat-suppression effects but tends to have a low signal-to-noise ratio, while the CHESS method does not provide sufficient fat suppression effects but tends to have a high signal-to-noise ratio. Although both methods have merits and demerits, we use the CHESS method for DWI because it can be used with the respiration synchronizing method to reduce the effects of respiratory movement in the chest and abdomen. However, the STIR method is used for DWI of the neck or pelvis.

As far as we know, no literature is available on DWI for peritoneal carcinomatosis. In the present study, all of the sites suspected to have peritoneal dissemination on CT, T1WI, and T2WI were clearly visualized as abnormal signals with clear contrast by DWI. Furthermore, disseminated lesions overlooked by CT or conventional MRI were detected by DWI, which demonstrates its usefulness.

A previous study reported a significant difference in ADC values between hepatic benign tumors and malignant tumors, including metastatic hepatic tumors and hepatocellular carcinoma (1.8 to 3.0×10^{-3} mm^2/sec vs. $0.8\text{-}1.7\times10^{-3}$ mm^2/sec)[24]. Kim et al.[25] reported a sensitivity of 98% and specificity of 80% in the differentiation of benign tumors from malignant hepatic tumors when a threshold value of ADC was set at 1.6×10^{-3} mm^2/sec. In the present study, the ADC values of the primary tumors and disseminated lesions were as low as $1.10\pm0.32\times10^{-3}$ mm^2/sec and $1.05\pm0.20\times10^{-3}$ mm^2/sec, respectively, with no significant difference. Both primary lesions and disseminated lesions had low ADC values, indicating malignant tumors.

There are two points to consider when interpreting DWI results. One is that it is sometimes difficult to distinguish disseminated lesions from intestinal contents that are visualized as abnormal signals. It is necessary to carefully compare DWI results with CT, T1WI, and T2WI to make a final decision. In such cases, the STIR method may be useful for suppressing the MRI signal of the intestinal contents[26]. It is also considered effective to administer a digestive tract negative contrast medium for MRI-manganese chloride tetrahydrate (Bothdel oral solution 10®; Kyowa Hakko, Tokyo, Japan). The other point is that it is necessary to differentiate disseminated lesions from lymph node metastasis visualized as an area of abnormal signal[26]. It is thought necessary to make an anatomic distinction by determining whether the abnormal signal is consistent with the lymphatic tract.

Conclusion

1. The present study was designed to verify the clinical usefulness of DWI in the diagnosis of peritoneal carcinomatosis compared with CT and conventional MRI techniques.
2. CT detected disseminated lesions in only three of five cases with large amounts of ascites. T1W and T2W imaging were inferior to CT in the detection of disseminated lesions.
3. DWI successfully visualized disseminated lesions with clear contrast against the surrounding area in all cases examined. Low ADC values suggesting malignant tumors were obtained.

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癌性腹膜炎における MRI 拡散強調像の有用性

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癌性腹膜炎に対し CT や従来の MRI 撮影法と拡散強調像を比較し、拡散強調像の有用性を検証した。対象は癌性腹膜炎の 6 症例で、原発巣の内訳は膵癌 3 例と大腸癌 1 例、卵巣癌 1 例、子宮体癌 1 例である。大量の腹水がみられた 3 例には、CT や MRI の T1 および T2 強調像で腹膜結節や大網結節、腸間壁肥厚の所見が認められ癌性腹膜炎が考えられた。明らかな腹水のない 1 例にも巨大な腹膜腫瘍がみられ、癌性腹膜炎が疑われた。一方、腹水が少量の 1 例と腹水のない 1 例には CT や MRI の T1 および T2 強調像から癌性腹膜炎を積極的に思わす所見は認められなかった。拡散強調像は白黒反転画像で表示したが、背景の信号が低いため、病変部と非病変部のコントラストが良好で、病変部の検出が容易であった。そのため CT や T1 および T2 強調像で認められた腹膜結節や大網結節、腸間壁肥厚だけではなく大網脂肪織の網状影にも異常信号が明瞭に認められ癌性腹膜炎が疑われた。また、何も所見のなかった 1 例にも腹膜播種や腸間膜播種が多数異常信号として描出された。みかけの拡散係数(ADC)マップから原発腫瘍と播種性病変の ADC 値を測定した結果は原発巣が $1.10\pm0.32\times10^{-3}$ mm²/sec で播種性病変が $1.05\pm0.20\times10^{-3}$ mm²/sec と有意差はなかった。また、両者とも悪性腫瘍を思わす低い値を呈した。拡散強調像は癌性腹膜炎の診断に有用性が高いが、読影する際に注意点が 2 点あった。1 つは腸管内容が異常信号として描出されることがあるため、腸管内容か播種性病変か慎重に判定する必要があった。もう 1 点は転移リンパ節も異常信号として描出されるため、播種性病変との鑑別が必要であった。

〈キーワード〉 癌性腹膜炎、MRI、拡散強調像