World Journal of Gastroenterology

Online Submissions: http://www.wjgnet.com/1007-9327office
wjg@wjgnet.com
doi:10.3748/wjg.v16.i7.832

World J Gastroenterol 2010 February 21; 16(7): 832-836
ISSN 1007-9327 (print)

REVIEW

Diffusion-weighted MRI in abdominal oncology: Clinical applications

Reiji Sugita, Kei Ito, Naotaka Fujita, Shoki Takahashi

Reiji Sugita, Department of Radiology, Sendai City Medical Center, Sendai 983-0824, Japan
Kei Ito, Naotaka Fujita, Department of Gastroenterology, Sendai City Medical Center, Sendai 983-0824, Japan
Shoki Takahashi, Department of Diagnostic Radiology, Graduate School of Medicine, Tohoku University, Sendai 980-8574, Japan
Author contributions: All authors wrote the manuscript.
Correspondence to: Reiji Sugita, MD, Department of Radiology, Sendai City Medical Center, Sendai 983-0824, Japan. rsugita@openhp.or.jp
Telephone: +81-22-2521111 Fax: +81-22-2529431
Received: September 17, 2009 Revised: November 12, 2009
Accepted: November 19, 2009
Published online: February 21, 2010

Abstract

Diffusion-weighted magnetic resonance imaging (DWI) provides image contrast that is different from that obtained by conventional magnetic resonance techniques. Although previously, DWI has been used to evaluate various diseases of the central nervous system, several technical advances have expanded the clinical applications of DWI beyond the central nervous system. As a result, many reports have been published on the use of DWI in abdominal diseases. Particularly, abdominal DWI has now being focused on evaluation of patients with abdominal cancer. DWI can be used for pretreatment tumor detection, characterization including predicting tumor response to therapy, monitoring tumor response during therapy, and follow-up study after treatment to detect possible tumor recurrence.

Key words: Diffusion weighted magnetic resonance imaging; Abdominal neoplasms

Peer reviewer: Xiao-Peng Zhang, Professor, Department of Radiology, Peking University School of Oncology, Beijing Cancer Hospital & Institute, No. 52 Haidian District, Beijing 100142, China

Sugita R, Ito K, Fujita N, Takahashi S. Diffusion-weighted MRI in abdominal oncology: Clinical applications. *World J Gastroenterol* 2010; 16(7): 832-836 Available from: URL: http://www.wjgnet.com/1007-9327/full/v16/i7/832.htm DOI: http://dx.doi.org/10.3748/wjg.v16.i7.832

INTRODUCTION

Diffusion-weighted magnetic resonance imaging (DWI) has enabled us to obtain additional information derived from the microscopic motion of water protons, which is not possible using conventional magnetic resonance imaging (MRI). Previously, DWI has been used to evaluate various diseases of the central nervous system. The most established clinical application of DWI for the central nervous system is evaluation of acute stroke[1].

DWI has many advantages. First, it is completely noninvasive, does not require exposure to ionizing radiation or injection of contrast material, and does not cause patient discomfort. Second, because it is derived from a well-established MRI technique, DWI does not require expert technicians with sophisticated technical skills or expensive equipment, such as a cyclotron that is required for positron emission tomography. Another advantage of DWI is that it can be added easily to a routine MRI protocol because it requires only a very short prolongation of examination time[2].

Recently, several technical advances have expanded the clinical applications of DWI beyond the central nervous system, and many studies have been published on the use of DWI in abdominal diseases. Particularly, abdominal DWI has now being focused on evaluating patients with abdominal cancer[3-9]. In this article, the application of DWI in abdominal oncology is described.

HOW TO INTERPRET DWI

DWI can offer qualitative and quantitative information

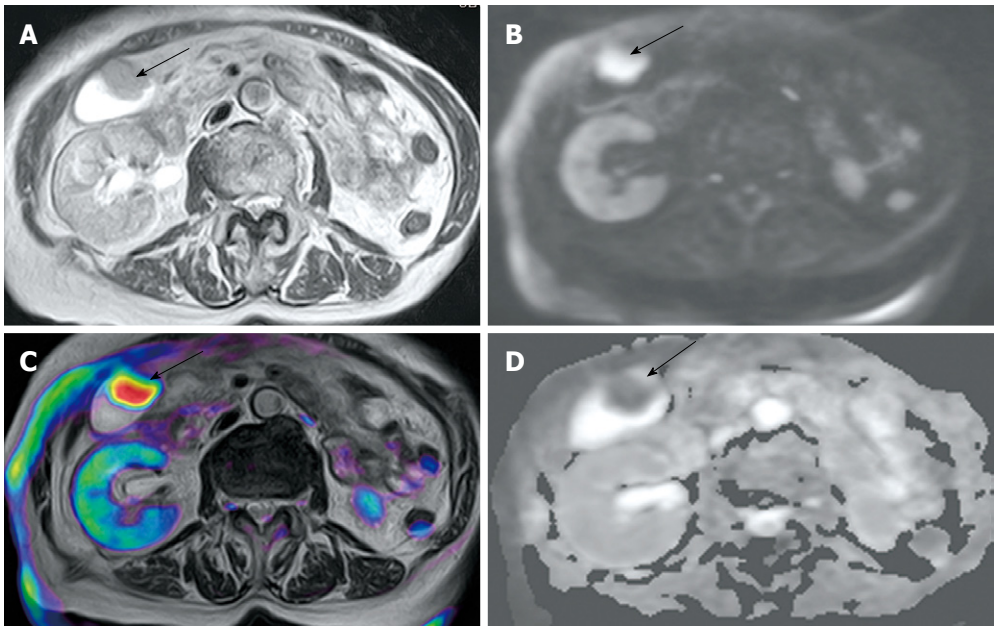

Figure 1 MRI of a patient with gallbladder carcinoma. A: Axial T2-weighted MRI of a patient with gallbladder carcinoma shows a mass (arrow) protruding into the gallbladder lumen; B: Corresponding axial DW image shows high intensity (arrow); C: Corresponding color fusion image of T2-weighted image and DW image shows gallbladder carcinoma (arrow). On color fusion images, the red area corresponds to high signal intensity on DW images and blue correspond to low intensity; D: Corresponding ADC map shows low intensity (arrow).

that can be helpful for tumor assessment (Figure 1). The former assesses visual differences in signal intensity between a tumor and its surrounding normal tissue, and the latter enables calculation of values (apparent diffusion coefficient, ADC) obtained from DWI, such as a computed tomography value.

Qualitative assessment in DWI

Visual assessment of relative tissue signal intensity on DWI is being used for tumor detection and characterization[3]. Tumors generally tend to block diffusion more than the tissue from which they originate and show relative high signal intensity on DWI (Figure 1B); however, some normal organs, such as the spleen, adrenal gland and seminal vesicle, also show high signal intensity on DWI. Moreover, DWI has a pitfall known as "T2 shine-through". DWI is obtained by adding a diffusion-weighting gradient (known as an MPG) to T2-weighted images, the basic sequence of conventional MRI. Thus, because DWI shows signal intensity that depends on diffusion and T2 signal intensity, a region with a high T2 signal retains the high signal on DWI, and may be mistaken for restricted diffusion. Therefore, special care must be taken with these pitfalls in diagnosing with DWI. DWI is usually interpreted by superimposing DWI and conventional morphological T2-weighted images because DWI cannot show minute morphological structures (Figure 1C).

Quantitative analysis in DWI

Quantitative tumor assessment is possible by calculating ADC after performing DWI with changed parameters (known as *b* values). ADC values in various malignant lesions generally tend to decrease, probably due to increased tissue cellularity or cell density, because the latter correlates with malignancy (Figure 1D). In addition to the cellular membranes, intracellular cytoskeleton, organelles, matrix fibers and soluble macromolecules contribute to diffusion restrictions in tumors[10]; therefore, ADC values are expected to reflect histopathological tissue characteristics. ADC is calculated for each pixel of the image and is displayed as a map. By setting regions of interest within tumors on these maps, ADCs of the tumor can be measured.

CLINICAL APPLICATIONS OF DWI IN ABDOMINAL ONCOLOGY

Tumor detection and characterization

Tumors generally tend to show relative high signal intensity on DWI. Using qualitative assessment, Nasu *et al*[11] have shown that DWI is superior to superparamagnetic iron oxide (SPIO)-enhanced MRI in detecting liver metastases, which had been the best available examination technique. They have reported that the sensitivity and specificity of DWI was 82% and 94%, respectively. Koh *et al*[12] also have reported that the sensitivity and specificity of DWI for detecting liver metastases was 78% and 95%. Thus, qualitative assessment with DWI has superior ability for assessing liver metastasis.

In colorectal tumors, Ichikawa *et al*[7] have shown that DWI has high sensitivity and specificity for detecting tumors, and several authors have shown that DWI has high sensitivity and specificity for detecting tumors even in the pancreatico-biliary system[6,9].

In quantitative assessment of DWI, ADC measurement has the potential to differentiate benign and malignant liver tumors. In many studies, malignancy has a lower ADC value than benignity. Taouli *et al*[13] have shown that metastatic liver tumors have the lowest ADC in malignant and benign focal lesions of the liver, and have revealed a significant difference between benign and malignant lesions. Chan *et al*[14] have shown that DWI can be used to distinguish between hepatic abscess and cystic or necrotic malignant liver tumor; ADC of abscess

cavities has a lower value than that of cystic or necrotic malignant liver tumors. Also in abdominal tumors other than in the liver, ADCs of malignant lesions have shown lower values[9,15,16]. However, most studies have reported that ADC measurement has no clear threshold to discriminate malignant and benign tumors because of substantial overlapping[9,13,15-18].

Predicting and monitoring response to therapy

Conventional criteria using morphological images have been used to evaluate antitumor therapy; however, measuring tumor size is often not adequate when tumors are treated with cytotoxic therapy and molecular targeting agents, because changes in tumor size after therapy with these drugs are not expected[4,19]; therefore, a new method for evaluating tumor response is required that can precisely reflects the clinical outcome, earlier than conventional imaging modalities.

The ability of DWI to predict therapy outcome has been shown in many clinical studies. Several authors have reported that tumors with low pretreatment ADC values show a better response to various therapies than those with high ADC[20-24]. However, studies of areas other than the abdomen have addressed that the relationship between pretreatment ADC and prognosis yield, with different results: patients suffering from a tumor with high pretreatment ADC show better long-term post-treatment prognosis than those with low ADC[25,26].

Many researchers have reported that DWI has the potential for evaluating tumor response during treatment. The results of animal studies have proved that ADC increases can be depicted in those responding to treatment[27]. In clinical studies, researchers have reported that an early increase in the ADC value after starting therapy suggests a better treatment outcome[20,28-32].

Monitoring response to therapy by visual assessment of DWI has been reported in brain tumors and bone metastasis, but not in the abdominal region[21,33]. Studies on bone metastasis have revealed that the treatment response after therapy could be assessed as a decrease in signal intensity[33]. Several authors have shown that tumors demonstrate an increase in ADC after treatment before a change in tumor size occurs, which heralds later diminution of the tumor size[18,22,34-38]. Chen *et al*[34] have reported that patients with hepatocellular carcinoma show a significant rise in ADC value when they respond to treatment. Koh *et al*[22] also have reported that patients with colorectal hepatic metastases show an increase in ADC, at least in those who show a partial response to treatment, but not in non-responders. A decrease in ADC during follow-up suggests tumor recurrence[27].

FUTURE DEVELOPMENT

Several studies have indicated that DWI may be useful for tumor staging, including lymph node and distant metastases[21,39-42]. For tumor staging, whole-body imaging is desirable. Takahara *et al* have shown that whole-body DWI is promising[43-45] using their method to examine the whole body by composite construction of segmented imaging. The images are processed using maximum intensity projection and 3D display[43-45]. More clinical research on this technique is needed because their study was preliminary.

The most important issue regarding DWI is non-standardization among MRI manufactures and researchers. Substantial differences in the ADC values of the same normal and diseased organs have been presented[5] by researchers using a different imaging technique; therefore, standardization of the imaging protocol is fundamental.

Currently, spatial resolution of DWI is not high enough. In order to compensate for such limited resolution, qualitative assessment might need superimposition of DWI on corresponding T2-weighted images, and quantitative assessment may require meticulous ADC measurements for small lesions. Utilization of high-field MRI may be able to solve the issue of limited spatial resolution.

CONCLUSION

DWI is a promising imaging technique to evaluate abdominal tumors. This technique can be used for pretreatment tumor detection, characterization including predicting tumor response to therapy, monitoring tumor response during therapy, and follow-up study after treatment to detect possible tumor recurrence. Standardization of the imaging protocol and large clinical trials regarding the usefulness of DWI are needed.

REFERENCES

1 **Schaefer PW**, Grant PE, Gonzalez RG. Diffusion-weighted MR imaging of the brain. *Radiology* 2000; **217**: 331-345
2 **Thoeny HC**, De Keyzer F. Extracranial applications of diffusion-weighted magnetic resonance imaging. *Eur Radiol* 2007; **17**: 1385-1393
3 **Koh DM**, Collins DJ. Diffusion-weighted MRI in the body: applications and challenges in oncology. *AJR Am J Roentgenol* 2007; **188**: 1622-1635
4 **Hamstra DA**, Rehemtulla A, Ross BD. Diffusion magnetic resonance imaging: a biomarker for treatment response in oncology. *J Clin Oncol* 2007; **25**: 4104-4109
5 **Padhani AR**, Liu G, Koh DM, Chenevert TL, Thoeny HC, Takahara T, Dzik-Jurasz A, Ross BD, Van Cauteren M, Collins D, Hammoud DA, Rustin GJ, Taouli B, Choyke PL. Diffusion-weighted magnetic resonance imaging as a cancer biomarker: consensus and recommendations. *Neoplasia* 2009; **11**: 102-125
6 **Ichikawa T**, Erturk SM, Motosugi U, Sou H, Iino H, Araki T, Fujii H. High-b value diffusion-weighted MRI for detecting pancreatic adenocarcinoma: preliminary results. *AJR Am J Roentgenol* 2007; **188**: 409-414
7 **Ichikawa T**, Erturk SM, Motosugi U, Sou H, Iino H, Araki T, Fujii H. High-B-value diffusion-weighted MRI in colorectal cancer. *AJR Am J Roentgenol* 2006; **187**: 181-184
8 **Naganawa S**, Sato C, Kumada H, Ishigaki T, Miura S, Takizawa O. Apparent diffusion coefficient in cervical cancer of the uterus: comparison with the normal uterine cervix. *Eur Radiol* 2005; **15**: 71-78
9 **Sugita R**, Yamazaki T, Furuta A, Itoh K, Fujita N, Takahashi

S. High b-value diffusion-weighted MRI for detecting gallbladder carcinoma: preliminary study and results. *Eur Radiol* 2009; **19**: 1794-1798
10 **Lyng H**, Haraldseth O, Rofstad EK. Measurement of cell density and necrotic fraction in human melanoma xenografts by diffusion weighted magnetic resonance imaging. *Magn Reson Med* 2000; **43**: 828-836
11 **Nasu K**, Kuroki Y, Nawano S, Kuroki S, Tsukamoto T, Yamamoto S, Motoori K, Ueda T. Hepatic metastases: diffusion-weighted sensitivity-encoding versus SPIO-enhanced MR imaging. *Radiology* 2006; **239**: 122-130
12 **Koh DM**, Brown G, Riddell AM, Scurr E, Collins DJ, Allen SD, Chau I, Cunningham D, deSouza NM, Leach MO, Husband JE. Detection of colorectal hepatic metastases using MnDPDP MR imaging and diffusion-weighted imaging (DWI) alone and in combination. *Eur Radiol* 2008; **18**: 903-910
13 **Taouli B**, Vilgrain V, Dumont E, Daire JL, Fan B, Menu Y. Evaluation of liver diffusion isotropy and characterization of focal hepatic lesions with two single-shot echo-planar MR imaging sequences: prospective study in 66 patients. *Radiology* 2003; **226**: 71-78
14 **Chan JH**, Tsui EY, Luk SH, Fung AS, Yuen MK, Szeto ML, Cheung YK, Wong KP. Diffusion-weighted MR imaging of the liver: distinguishing hepatic abscess from cystic or necrotic tumor. *Abdom Imaging* 2001; **26**: 161-165
15 **Kim T**, Murakami T, Takahashi S, Hori M, Tsuda K, Nakamura H. Diffusion-weighted single-shot echoplanar MR imaging for liver disease. *AJR Am J Roentgenol* 1999; **173**: 393-398
16 **Yamada I**, Aung W, Himeno Y, Nakagawa T, Shibuya H. Diffusion coefficients in abdominal organs and hepatic lesions: evaluation with intravoxel incoherent motion echo-planar MR imaging. *Radiology* 1999; **210**: 617-623
17 **van Rijswijk CS**, Kunz P, Hogendoorn PC, Taminiau AH, Doornbos J, Bloem JL. Diffusion-weighted MRI in the characterization of soft-tissue tumors. *J Magn Reson Imaging* 2002; **15**: 302-307
18 **Einarsdóttir H**, Karlsson M, Wejde J, Bauer HC. Diffusion-weighted MRI of soft tissue tumours. *Eur Radiol* 2004; **14**: 959-963
19 **Thoeny HC**, De Keyzer F, Vandecaveye V, Chen F, Sun X, Bosmans H, Hermans R, Verbeken EK, Boesch C, Marchal G, Landuyt W, Ni Y. Effect of vascular targeting agent in rat tumor model: dynamic contrast-enhanced versus diffusion-weighted MR imaging. *Radiology* 2005; **237**: 492-499
20 **Cui Y**, Zhang XP, Sun YS, Tang L, Shen L. Apparent diffusion coefficient: potential imaging biomarker for prediction and early detection of response to chemotherapy in hepatic metastases. *Radiology* 2008; **248**: 894-900
21 **Mardor Y**, Roth Y, Ochershvilli A, Spiegelmann R, Tichler T, Daniels D, Maier SE, Nissim O, Ram Z, Baram J, Orenstein A, Pfeffer R. Pretreatment prediction of brain tumors' response to radiation therapy using high b-value diffusion-weighted MRI. *Neoplasia* 2004; **6**: 136-142
22 **Koh DM**, Scurr E, Collins D, Kanber B, Norman A, Leach MO, Husband JE. Predicting response of colorectal hepatic metastasis: value of pretreatment apparent diffusion coefficients. *AJR Am J Roentgenol* 2007; **188**: 1001-1008
23 **DeVries A**, Kremser C, Hein P, Griebel J, Krezcy A, Öfner D, Pfeiffer K, Lukas P, Judmaier W. Tumor microcirculation and diffusion predict therapy outcome for primary rectal carcinoma1. *Int J Radiat Oncol Biol Phys* 2003; **56**: 958-965
24 **Dzik-Jurasz A**, Domenig C, George M, Wolber J, Padhani A, Brown G, Doran S. Diffusion MRI for prediction of response of rectal cancer to chemoradiation. *Lancet* 2002; **360**: 307-308
25 **Higano S**, Yun X, Kumabe T, Watanabe M, Mugikura S, Umetsu A, Sato A, Yamada T, Takahashi S. Malignant astrocytic tumors: clinical importance of apparent diffusion coefficient in prediction of grade and prognosis. *Radiology* 2006; **241**: 839-846
26 **Murakami R**, Sugahara T, Nakamura H, Hirai T, Kitajima M, Hayashida Y, Baba Y, Oya N, Kuratsu J, Yamashita Y. Malignant supratentorial astrocytoma treated with postoperative radiation therapy: prognostic value of pretreatment quantitative diffusion-weighted MR imaging. *Radiology* 2007; **243**: 493-499
27 **Thoeny HC**, De Keyzer F, Chen F, Ni Y, Landuyt W, Verbeken EK, Bosmans H, Marchal G, Hermans R. Diffusion-weighted MR imaging in monitoring the effect of a vascular targeting agent on rhabdomyosarcoma in rats. *Radiology* 2005; **234**: 756-764
28 **Moffat BA**, Chenevert TL, Lawrence TS, Meyer CR, Johnson TD, Dong Q, Tsien C, Mukherji S, Quint DJ, Gebarski SS, Robertson PL, Junck LR, Rehemtulla A, Ross BD. Functional diffusion map: a noninvasive MRI biomarker for early stratification of clinical brain tumor response. *Proc Natl Acad Sci USA* 2005; **102**: 5524-5529
29 **Chenevert TL**, McKeever PE, Ross BD. Monitoring early response of experimental brain tumors to therapy using diffusion magnetic resonance imaging. *Clin Cancer Res* 1997; **3**: 1457-1466
30 **Kremser C**, Judmaier W, Hein P, Griebel J, Lukas P, de Vries A. Preliminary results on the influence of chemoradiation on apparent diffusion coefficients of primary rectal carcinoma measured by magnetic resonance imaging. *Strahlenther Onkol* 2003; **179**: 641-649
31 **Theilmann RJ**, Borders R, Trouard TP, Xia G, Outwater E, Ranger-Moore J, Gillies RJ, Stopeck A. Changes in water mobility measured by diffusion MRI predict response of metastatic breast cancer to chemotherapy. *Neoplasia* 2004; **6**: 831-837
32 **Lee KC,** Bradley DA, Hussain M, Meyer CR, Chenevert TL, Jacobson JA, Johnson TD, Galban CJ, Rehemtulla A, Pienta KJ, Ross BD. A feasibility study evaluating the functional diffusion map as a predictive imaging biomarker for detection of treatment response in a patient with metastatic prostate cancer to the bone. *Neoplasia* 2007; **9**: 1003-1011
33 **Byun WM**, Shin SO, Chang Y, Lee SJ, Finsterbusch J, Frahm J. Diffusion-weighted MR imaging of metastatic disease of the spine: assessment of response to therapy. *AJNR Am J Neuroradiol* 2002; **23**: 906-912
34 **Chen CY**, Li CW, Kuo YT, Jaw TS, Wu DK, Jao JC, Hsu JS, Liu GC. Early response of hepatocellular carcinoma to transcatheter arterial chemoembolization: choline levels and MR diffusion constants--initial experience. *Radiology* 2006; **239**: 448-456
35 **Kamel IR**, Bluemke DA, Eng J, Liapi E, Messersmith W, Reyes DK, Geschwind JF. The role of functional MR imaging in the assessment of tumor response after chemoembolization in patients with hepatocellular carcinoma. *J Vasc Interv Radiol* 2006; **17**: 505-512
36 **Deng J**, Miller FH, Rhee TK, Sato KT, Mulcahy MF, Kulik LM, Salem R, Omary RA, Larson AC. Diffusion-weighted MR imaging for determination of hepatocellular carcinoma response to yttrium-90 radioembolization. *J Vasc Interv Radiol* 2006; **17**: 1195-1200
37 **Kamel IR**, Reyes DK, Liapi E, Bluemke DA, Geschwind JF. Functional MR imaging assessment of tumor response after 90Y microsphere treatment in patients with unresectable hepatocellular carcinoma. *J Vasc Interv Radiol* 2007; **18**: 49-56
38 **Kamel IR**, Bluemke DA, Ramsey D, Abusedera M, Torbenson M, Eng J, Szarf G, Geschwind JF. Role of diffusion-weighted imaging in estimating tumor necrosis after chemoembolization of hepatocellular carcinoma. *AJR Am J Roentgenol* 2003; **181**: 708-710
39 **Choi EK**, Kim JK, Choi HJ, Park SH, Park BW, Kim N, Kim JS, Im KC, Cho G, Cho KS. Node-by-node correlation between MR and PET/CT in patients with uterine cervical cancer: diffusion-weighted imaging versus size-based

criteria on T2WI. *Eur Radiol* 2009; **19**: 2024-2032
40 **Herneth AM**, Philipp MO, Naude J, Funovics M, Beichel RR, Bammer R, Imhof H. Vertebral metastases: assessment with apparent diffusion coefficient. *Radiology* 2002; **225**: 889-894
41 **Baur A**, Stäbler A, Brüning R, Bartl R, Krödel A, Reiser M, Deimling M. Diffusion-weighted MR imaging of bone marrow: differentiation of benign versus pathologic compression fractures. *Radiology* 1998; **207**: 349-356
42 **Baur A**, Huber A, Ertl-Wagner B, Dürr R, Zysk S, Arbogast S, Deimling M, Reiser M. Diagnostic value of increased diffusion weighting of a steady-state free precession sequence for differentiating acute benign osteoporotic fractures from pathologic vertebral compression fractures. *AJNR Am J Neuroradiol* 2001; **22**: 366-372
43 **Takahara T**, Imai Y, Yamashita T, Yasuda S, Nasu S, Van Cauteren M. Diffusion weighted whole body imaging with background body signal suppression (DWIBS): technical improvement using free breathing, STIR and high resolution 3D display. *Radiat Med* 2004; **22**: 275-282
44 **Kwee TC**, Takahara T, Ochiai R, Nievelstein RA, Luijten PR. Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS): features and potential applications in oncology. *Eur Radiol* 2008; **18**: 1937-1952
45 **Li S**, Sun F, Jin ZY, Xue HD, Li ML. Whole-body diffusion-weighted imaging: technical improvement and preliminary results. *J Magn Reson Imaging* 2007; **26**: 1139-1144

S- Editor Tian L **L- Editor** Kerr C **E- Editor** Ma WH