Small hypervascular hepatocellular carcinomas: value of diffusion-weighted imaging compared with “washout” appearance on dynamic MRI

^{1,2}D J KIM, MD, ¹J-S YU, MD, ¹J H KIM, MD, ¹J-J CHUNG, MD and ¹K W KIM, MD

¹Department of Radiology and the Research Institute of Radiological Science, Yonsei University College of Medicine, Gangnam Severance Hospital, Seoul, Republic of Korea, and ²Department of Radiology, CHA Bundang Medical Center, CHA University, Seoul, Republic of Korea

Objective: To compare the value of diffusion-weighted MRI (DWI) with the venous “washout” appearance during dynamic MRI for the assessment of small arterial hypervascular lesions in cirrhotic liver.

Methods: After exclusion of benign hypervascular lesions, including haemangiomas and subcapsular non-tumorous arteriportal shunts, indicated by typical imaging features, a total of 109 small arterial hypervascular lesions (0.5–3.0 cm in the longest diameter) in 65 patients with cirrhosis who underwent gadopentetate dimeglumine-enhanced dynamic MRI and DWI ($b=50, 400, 800 \text{ s mm}^{-2}$) at 1.5 T during a 16-month period were retrospectively analysed to determine the presence of venous washout during dynamic imaging or sustained hyperintensity upon increasing the b factor size on DWI.

Results: Among the 99 hypervascular hepatocellular carcinomas (HCCs), sustained hyperintensity on DWI (92/99, 93%) was more prevalent than the washout appearance (72/99, 72%) on dynamic MRI ($p<0.001$). Depending on the lesion size, subcentimetre-sized HCCs had a significantly lower prevalence of venous washout (13/30, 43%) than the sustained hyperintensity on DWI (27/30, 90%) ($p=0.001$). In all 10 hypervascular benign conditions, there was no venous washout on dynamic MRI and no sustained hyperintensity on DWI. Sensitivity and specificity for diagnosis of hypervascular HCCs were 92.9% and 100% in DWI and 72% and 100% in dynamic MRI, respectively.

Conclusion: Compared with the venous washout during dynamic imaging, DWI provides more reliable information in the MRI assessment of small hypervascular HCCs, distinguishing them from atypical hypervascular benign or pseudolesions. DWI could complement the early diagnosis of small hypervascular HCCs that do not display venous washout during dynamic imaging.

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The typical haemodynamic pattern of arterial hypervascular enhancement and venous washout on dynamic imaging is usually applied to characterise hepatocellular carcinoma (HCC) in the cirrhotic liver. In clinical practice, however, it is not always easy to discern venous washout, especially for small (≤ 2 cm in the longest diameter) HCCs on dynamic CT or MRI [1–3]. With the technical advances in MRI, diffusion-weighted MRI (DWI) can be applied to liver imaging for the assessment of focal lesions, which relies upon restricted water diffusion in malignant lesions including HCCs. Recently, several studies have demonstrated the feasibility of DWI for the detection and characterisation of liver tumours [4–11], and some reports showed that DWI improves the detection rate of HCCs in the cirrhotic liver [7–11]. In this study, we retrospectively validate DWI in comparison with the venous washout

appearance during dynamic MRI for the assessment of small hypervascular lesions in cirrhotic liver.

Methods and materials

Patient populations

A retrospective study was designed from November 2008 to February 2010 after approval by the institutional review board. During this period, a study co-ordinator, who did not analyse the MR images, reviewed all hepatic MRI interpretation records in patients ($n=120$) with cirrhosis. In order to be enrolled in this study, patients had to have at least one hypervascular lesion in the cirrhotic background of the liver, ranging from 0.5 to 3 cm in the longest diameter, observable during the arterial phase of dynamic MRI. Such lesions had to be verified histologically or via serial follow-up imaging studies. During the analysis of follow-up imaging, we defined HCCs according to the following criteria: typical tumour staining on hepatic arteriography with sustained nodular iodised oil accumulations on serial follow-up CT

Address correspondence to: Professor Jeong-Sik Yu, Department of Radiology and the Research Institute of Radiological Science, Yonsei University College of Medicine, Gangnam Severance Hospital, 712 Eonjuro, Gangnam-Gu, Seoul 135-720, Republic of Korea. E-mail: yjsrad97@yuhs.ac

after chemoembolisation therapy, or progression of lesion size (>20%) on serial follow-up CT or MRI (over at least a 6-month period). We defined hypervascular benign or pseudolesions using the following criteria: no change or a decrease in lesion size or disappearance of the lesion on serial follow-up CT (at least 12 months or longer). We excluded typical haemangiomas depending on the imaging findings: bright hyperintensity on T_2 weighted images and gradual peripheral, globular and centrifugal enhancement or the bright dot sign on dynamic enhancing MRI [12]. Typical non-tumorous arterioportal venous shunts were also excluded in the presence of the following imaging findings: a subcapsular wedge-shaped arterial enhancement area in the liver without any distinguishable abnormal signal intensity on the pre-contrast T_1 and T_2 weighted images in addition to equilibrium phase post-contrast images [13]. All of the pre-excluded lesions were verified again by no change or disappearance on follow-up imaging studies. The final study population consisted of 65 patients with cirrhosis (52 males and 13 females), ranging in age from 37 to 82 years, with 109 hypervascular lesions (Figure 1). The causes of cirrhosis in the study population were hepatitis B ($n=45$), hepatitis C ($n=14$) and alcohol abuse ($n=1$), or were cryptogenic ($n=5$).

MRI techniques

MRI was performed using a 1.5T system (Magnetom Avanto; Siemens Healthcare, Erlangen, Germany) with a six-element phased-array surface coil. First, spectrally fat-suppressed breath-hold half-Fourier single-shot turbo spin echo (HASTE) images [repetition time (TR), infinite; echo time (TE), 85 ms; slice thickness, 6–8 mm] and a double-echo chemical shift gradient echo (GRE) sequence [TR, 100 ms; first echo TE, 2.0 ms (opposed phase), second echo TE, 4.2 ms (in phase); flip angle, 70°]

were obtained in the axial plane. After an intravenous injection of 15 ml of gadopentetate dimeglumine (Magnevist®; Bayer Healthcare, Berlin, Germany) with a 3 ml s^{-1} injection speed through the antecubital vein followed by saline flush, dynamic contrast-enhanced imaging was performed using a three-dimensional (3D) GRE sequence (VIBE; volumetric interpolated breath-hold examination) with ultrafast image reconstruction by parallel imaging algorithms [generalised autocalibrating partially parallel acquisition (GRAPPA) factor, 2] in the axial plane [TR, 4.4 ms; TE, 2.1 ms; flip angle, 10°; matrix, 448×224 ; field of view (FOV), $271 \times 379 \text{ mm}$; slice thickness, 5 mm; slice spacing, 2.5 mm; slices, 72] during a 20-s breath-holding period. A dynamic series consisted of one pre-contrast series followed by three successive post-contrast series including early arterial, late arterial and portal phase imaging with 34-s intervals (20 s for image acquisition with breath-holding and 14 s for rebreathing) for the start of each phase imaging followed by 5-min delayed-phase imaging. For determination of the time delay for the early arterial phase imaging, a timing examination was performed according to a previously described method [14].

DWI was performed before the dynamic imaging using a single-shot spin echo echoplanar imaging (EPI) sequence that combined the two diffusion (motion probing) gradients before and after the 180° pulse along the three directions of section select, phase encoding and frequency encoding. Data acquisition with an EPI readout was obtained by applying three different b factors of 50, 400 and 800 s mm^{-2} . A GRAPPA algorithm of parallel imaging with an acceleration factor of 2 was added to reduce the acquisition time. Spectral fat saturation was used systematically to suppress chemical shift artefacts. The sequence was obtained within a free-breathing method with a navigator system (respiratory triggering system). The technical parameters of the navigator system were: TR, 3900 ms; TE, 75 ms; FOV, 360–400 mm; matrix, 156×192 ; slices, 78 (26 slices for each b factor); thickness, 6 mm; interslice gap, 1.2 mm; number of excitations, 4; bandwidth, 1736 Hz per pixel; and acquisition time, 4–5 min.

Image analysis

During the lesion selection, the study co-ordinator marked the hypervascular lesions with electronic arrows and measured the longest diameter of the lesions with electronic calipers on the arterial phase images of dynamic MRI and then saved the measurements on a picture archiving and communicating system. Two radiologists (one with 5 years and one with more than 10 years of experience in liver MRI interpretation), who did not select the lesions, determined with consensus the presence of washout corresponding to the marked lesions on the arterial phase images and on portal and equilibrium phase images of dynamic MRI, without any additional information. Hypointensity in the area of the corresponding hypervascular lesion was regarded as washout, compared with the background parenchyma. Also, the presence of peripheral rim enhancement, suggesting coronal enhancement of the draining portal venules into the pseudocapsule during the portal venous phase or a remaining circumferential enhancement

Figure 1. Flow chart of patient selection and overall study design. HCC, hepatocellular carcinoma; TACE, transcatheter arterial chemoembolisation.

greater than the tumour portion on the equilibrium phase images, was also regarded as indicative of washout [3, 15]. During the image analysis, pre-contrast T_1 weighted dynamic images and T_2 weighted images were also evaluated. After 1 month, DWI was also reviewed by the same radiologists with consensus for sustained hyperintensity with increasing b factor size in the same hypervascular lesions, without any additional information. Also, pre-contrast T_1 weighted dynamic images and T_2 weighted images were evaluated.

Data analysis

In small HCCs, we evaluated the differences in proportion between washout on dynamic imaging and sustaining hyperintensity on DWI. The McNemar test was performed in four separate HCC groups according to the longest dimension of each lesion measured on the arterial phase images of dynamic MRI (<10 mm, 10–14 mm, 15–20 mm, >20 mm). A likelihood ratio χ^2 test was performed to evaluate the correlation between lesion size and the presence of washout on dynamic imaging or hyperintensity on DWI. The χ^2 test was carried out for evaluation of the association between the preliminarily determined signal characteristics of pre-contrast T_1 weighted hypointensity or T_2 weighted hyperintensity and the presence of washout on dynamic MRI or hyperintensity on DWI, regardless of lesion size. In all statistical analyses, differences were considered significant when the p -value was <0.05. We calculated the sensitivity and specificity of DWI and dynamic MRI compared with the results of arterial hypervascular lesions (HCC or pseudolesion).

Results

Among the 109 arterial hypervascular lesions, 10 hypervascular lesions were verified as benign or pseudolesions according to serial follow-up imaging studies, and 99 lesions were verified as HCCs histologically ($n=21$) or through serial follow-up CT studies (iodised oil deposition after chemoembolisation or >20% increase in diameter, $n=78$).

Sustained hyperintensity on DWI (92/99, 93%) was more prevalent than a washout appearance (72/99, 72%) on dynamic MRI ($p<0.001$). Depending on the sizes of the lesions, subcentimetre HCCs had a significantly lower prevalence of venous washout (13/30, 43%) than hyperintensity on DWI (27/30, 90%) ($p=0.001$). As the lesion size increased, the prevalence of washout on dynamic imaging increased ($p<0.001$), but there was no change in the prevalence of hyperintensity on DWI ($p=0.180$) (Figures 2–4, Table 1). In all hypervascular benign lesions or pseudolesions ($n=10$), there was no venous washout on dynamic MRI, no hypointensity on T_1 weighted imaging, no hyperintensity on T_2 weighted imaging and no sustained hyperintensity on DWI (Figure 5).

The prevalence of washout on dynamic MRI or hyperintensity on DWI was high, compared with the prevalence of T_1 weighted hypointensity or T_2 weighted hyperintensity on pre-contrast images (Tables 1 and 2). Washout on dynamic MRI showed significant association

with pre-contrast T_1 weighted hypointensity ($p<0.001$). There was no significant association between hyperintensity on DWI and T_2 weighted hyperintensity on pre-contrast images ($p>0.05$; Table 3). The sensitivity and specificity for the diagnosis of hypervascular HCCs were 92.9% and 100% in DWI and 72% and 100% in dynamic MRI, respectively.

Discussion

Early detection of small HCCs is crucial in patients with cirrhosis in order to plan effective treatment—such as resection, transplantation, tumour ablation or chemoembolisation—and to improve the prognosis [16, 17]. Several imaging modalities are used in patients with cirrhosis for early detection of small HCCs; however, the differentiation of nodular lesions, such as regenerative nodules, dysplastic nodules and small HCCs, can sometimes be a diagnostic challenge. MRI is superior to other imaging modalities for the early detection and differentiation of nodular lesions. Furthermore, there are various techniques used in MRI for the detection and characterisation of nodular lesions in the liver to improve the detectability of small HCCs [17, 18]. DWI has been suggested to be useful for characterising focal hepatic lesions and improving detectability of small HCCs [4–11]. Xu et al [7] reported that dynamic MRI with combined DWI revealed higher lesion detection sensitivity (97%) than dynamic MRI alone (85%). Even in the detection of subcentimetre intrahepatic metastases from HCCs, DWI showed merit compared with dynamic MRI alone in a recent report by Yu et al [8]. With the addition of DWI to conventional diagnostic criteria (arterial hypervascularity and subsequent washout) in a recent study by Piana et al [9], the sensitivity of the combined interpretation of DWI with dynamic MRI (arterial hypervascularity plus subsequent washout or DWI hyperintensity) was considerably increased (85%) compared with dynamic MRI alone (60%), regardless of the size of HCCs. In the present study, we also found that DWI provided additional information to that provided by dynamic MRI in the diagnosis of hypervascular HCCs, especially for lesions <1.5 cm. In addition, Nishie et al [10] reported that superparamagnetic iron oxide (SPIO)-enhanced MRI combined with DWI (sensitivity, specificity, positive predictive value and negative predictive value for detection of HCCs were 70%, 98.6%, 92.9% and 92.4%, respectively) was superior to SPIO-enhanced MRI alone (sensitivity, specificity, positive predictive value and negative predictive value for detection of HCCs were 66%, 98%, 90% and 91.4%, respectively). Kim et al [11] also reported the supplementary value of hyperintensity on T_2 weighted imaging and DWI in the diagnosis of hypervascular subcentimetre HCCs compared with MRI with gadoxetic acid as a liver-specific contrast agent.

DWI is based on the dephasing effect of extracellular water molecules through Brownian motion. Also, DWI hyperintensity reflects high cellular density and structural distortion (diffusion restriction) with or without the T_2 shine-through effect, which we suggest to be a malignant lesion in the liver. In malignant lesions, the contrast-to-noise ratio of DWI has been reported to be

Figure 2. Subcentimetre hypervascular hepatocellular carcinomas have a significantly lower prevalence of venous washout (13/30, 43%) than hyperintensity on diffusion-weighted MRI (DWI) (27/30, 90%) ($p=0.001$). As the lesion size increases, the washout prevalence on dynamic imaging ($p<0.001$) increases, but there is no significant change in the prevalence of hyperintensity on DWI ($p=0.180$).

higher than that of conventional T_2 weighted images [19, 20]. The advances in MRI technology, such as high-performance gradient coils, parallel imaging techniques and multiple phased-array receiver coils, have enabled DWI to be applied to abdominal imaging with improved image quality [21, 22]. The lower b factors ($<100 \text{ s mm}^{-2}$) of DWI with a high signal-to-noise ratio demonstrate high sensitivity for lesion detection through the signal nullification of the intrahepatic vasculature. In addition, higher b factors ($>500 \text{ s mm}^{-2}$) have merit in lesion characterisation by signal suppression of benign lesions of cysts or haemangiomas [5, 23]. In the cirrhotic liver, the background hepatic parenchyma could show heterogeneous signal intensities on DWI because of liver fibrosis or inflammation [24]. However, DWI using high b factors overcomes these handicaps and improves HCC delineation with excellent conspicuity owing to the dark background signals [8]. Unfortunately, DWI is vulnerable to other kinds of motions, producing artefacts. In this study, a few HCCs could not be detected using DWI, because of its extreme sensitivity to the physiological motion of cardiac pulsation (Figure 4); these lesions were mostly located in the left lobe of the liver beneath the diaphragm. In the present study, a respiration-triggered technique was used for DWI because of the potential to improve image quality by a higher signal-to-noise ratio and apparent diffusion coefficient (ADC) quantifications with a higher number of excitations than the breath-hold

technique, even though the imaging time of the respiration-triggered method was much longer [5, 25, 26]. We also tried to determine the association between the T_2 weighted hyperintensity and the hyperintensity on DWI because DWI reflects the T_2 as well as the degree of molecular diffusion. Because of the low lesion-to-liver contrast of solid lesions in the single-shot fast spin echo sequence that we used, especially in the inhomogeneous background of cirrhotic liver, T_2 weighted hyperintensity was barely depicted in any of the lesions in the present study (Table 3).

The typical diagnostic finding of venous washout on contrast-enhanced dynamic MRI is still used as the diagnostic standard of HCCs without biopsy confirmation [1]. Yu et al [3] reported that the hypointensity of the portal phase of dynamic MRI, hypointensity of the delayed phase of dynamic MRI and rim enhancement were 11%, 29% and 18%, respectively, in subcentimetre hypervascular HCCs. In the present study, 43% of subcentimetre hypervascular HCCs demonstrated washout on dynamic MRI. In the previous study [3], two-dimensional GRE imaging was used for dynamic MRI with an $8 \times 10 \text{ mm}$ slice thickness and a 1.6–2.0 mm intersection gap. Compared with the results of the previous study [3], our study demonstrated improvement in the washout detection rates on dynamic MRI in subcentimetre hypervascular HCCs with the use of 3D GRE imaging. We used a thinner image slice without an

Figure 3. A 70-year-old male with a small hypervascular hepatocellular carcinoma in the cirrhotic liver. (a) There is no prominent hypointensity lesion on the pre-contrast T_1 weighted image. (b) A hyperintensity lesion is revealed in the dome area of the right lobe of the liver on the pre-contrast T_2 weighted image (arrow). (c) A 1.7-cm hypervascular lesion is noted in the dome area of the right lobe of the liver on an arterial phase image obtained using dynamic MRI (arrow). (d) This lesion shows no subsequent washout in the delayed phase of dynamic MRI. (e) A hyperintense lesion is demonstrated in the same area of the liver dome on diffusion-weighted MRI (b factor= 800 s mm^{-2}) (arrow). (f) After chemoembolisation, a follow-up CT scan shows an iodised oil deposition in the same lesion (arrow).

Figure 4. A 55-year-old male with a small hypervascular hepatocellular carcinoma (HCC) in the cirrhotic liver. (a) There is no prominent hypointensity lesion on the pre-contrast T_1 weighted image. (b) There is no prominent hyperintensity lesion on the pre-contrast T_2 weighted image. (c) A 1.6-cm hypervascular lesion is demonstrated in the left lobe of the liver on an arterial phase dynamic MR image (arrow). (d) This lesion reveals subsequent washout on a delayed phase dynamic MR image (arrow). (e) A hyperintense lesion is not revealed in the same area on diffusion-weighted MRI (b factor= 800 s mm^{-2}). (f) This lesion is a pathologically confirmed HCC (arrow).

Table 1. Number of lesions (%) showing hyperintensity on diffusion-weighted MRI (DWI) and venous washout on dynamic MRI according to the size of hypervascular hepatocellular carcinomas

Lesion (size of lesion)	Hyperintensity on DWI ^a	Venous washout on dynamic MRI ^b	p-value ^c
5–9 mm (n=30)	27 (90%)	13 (43%)	0.001
10–14 mm (n=24)	22 (92%)	17 (71%)	0.180
15–19 mm (n=19)	18 (95%)	18 (95%)	1.000
20–30 mm (n=25)	25 (100%)	24 (96%)	1.000
Total (n=99)	92 (93%)	72 (72%)	<0.001

^aOn DWI, sustained high signal intensity regardless of *b* value size.

^bWashout revealed hypointensity or rim pseudocapsule on the portal or equilibrium phases of dynamic MRI.

^cMcNemar test for comparing the proportion of washout with high signal intensity on DWI in each group.

intersection gap, minimising the partial volume effect of the background parenchyma, to improve the detection rate of washout for the subcentimetre lesions. For the strong association between the T_1 weighted hypointensity and washout on dynamic MRI ($p<0.001$), we consider that the inherent hypointensity could be more easily distinguished from the surrounding hepatic parenchyma even on post-contrast images when the contrast material is washed out from individual lesions compared with the iso- or hyperintense lesions on pre-contrast T_1 weighted imaging [3].

There are considerable numbers of hypervascular HCCs that do not show subsequent washout despite the advances in MRI techniques; therefore, hyperintensity on a T_2 weighted image is sometimes helpful for diagnosis [27]. Because of variable signal intensities, however, some small HCCs cannot be characterised on T_2 weighted images [28]. In the present study, most of

the small hypervascular HCCs revealed hyperintensity on DWI, and DWI could be very useful for assessment of small HCCs that do not show washout during dynamic MRI.

Shimizu et al [29] reported that round or oval small arterial enhancing lesions ($n=104$) were confirmed as either HCCs (28%) or benign or pseudolesions (72%). In this study, we excluded typical wedge-shaped early arterial enhancing lesions and haemangiomas; however, many lesions were verified as HCCs, with only a small number of lesions ($n=10$) verified as benign or pseudolesions. The sizes of the lesions ranged from 5 to 30 mm. Holland et al [30] reported that only small arterial enhancing lesions without venous washout on dynamic imaging and that were occult on T_2 weighted images were mostly non-neoplastic lesions (93%). Kanematsu et al [31] reported that 26% of the early enhancing non-neoplastic lesions yielded a slightly hyperintense signal

Figure 5. A 45-year-old male with a hypervascular pseudolesion in the cirrhotic liver. (a) There is no prominent hypointensity lesion on the pre-contrast T_1 weighted image. (b) There is no prominent hyperintensity lesion on the pre-contrast T_2 weighted image. (c) A 1.2-cm hypervascular lesion is noted in segment 8 of the liver on an arterial phase dynamic MR image (arrow). (d) This lesion reveals no subsequent washout on the delayed phase image of dynamic MRI. (e) A hyperintense lesion is not revealed in the same area on diffusion-weighted MRI (b factor = 800 s mm^{-2}). (f) A 12-month follow-up CT shows a similar lesion (arrow) defined only on the arterial phase images. Because there was no change on the long-term follow-up images, this was regarded as a benign condition such as a focal perfusional variation.

Table 2. Number of lesions (%) showing hyperintensity on pre-contrast T_2 weighted imaging and hypointensity on pre-contrast T_1 weighted imaging according to the size of hypervascular hepatocellular carcinomas

Lesion (size of lesion)	T_2 weighted imaging ^a	T_1 weighted imaging ^b
5–9 mm ($n=30$)	12 (40%)	12 (40%)
10–14 mm ($n=24$)	18 (94%)	14 (73%)
15–19 mm ($n=19$)	18 (72%)	17 (68%)
20–30 mm ($n=25$)	23 (92%)	22 (88%)
Total ($n=99$)	71 (72%)	65 (66%)

^aNumber of hyperintense lesions on T_2 weighted images.^bNumber of hypointense lesions on pre-contrast T_1 weighted images.

on T_2 weighted images. In the present study, although hypervascular benign or pseudolesions were small in number, no lesions showed venous washout on dynamic imaging or sustained hyperintensity on DWI.

Our study had several limitations. First, pathological confirmation was not available for many lesions, for which diagnosis was based on serial follow-up examinations, including increasing size and iodised oil accumulation after chemoembolisation therapy. DWI features could be influenced by tumour grade and differentiation, but many lesions were not available for evaluation of tumour grade and differentiation. Further study is needed. Many HCCs were not correlated with borderline malignant lesions, such as hypervascular dysplastic nodules, and unusual manifestation of benign lesions, such as unusual enhancement patterns of haemangiomas, was not completely excluded in this study. In particular, haemangiomas were discussed on serial follow-up examination as a result of iodised oil accumulations, but haemangiomas were well separated according to typical MRI and angiographic findings [32]. Second, we did not measure ADC values in each lesion because of the large number of subcentimetre lesions, which are potentially of limited

Table 3. Prevalence of washout on dynamic MRI or hyperintensity on diffusion-weighted MRI (DWI), according to the pre-contrast T_1 and T_2 weighted imaging features of hypervascular hepatocellular carcinomas

	Washout (+) ^c	Washout (–)	DWI (+) ^d	DWI (–)
T_1 , low (+) ^a	58	7	61	4
T_1 , low (–)	15	19	31	3
	$p<0.001$		$p=0.689$	
T_2 , high (+) ^b	60	11	67	4
T_2 , high (–)	13	15	25	3
	$p<0.001$		$p=0.400$	

Numbers are the number of lesions.

The Pearson χ^2 test was performed for evaluation of the association between the preliminarily determined signal characteristics of pre-contrast T_1 weighted hypointensity or T_2 weighted hyperintensity and the presence of washout on dynamic MRI or hyperintensity on DWI.

^aHypointensity on pre-contrast T_1 weighted images.^bHyperintensity on pre-contrast T_2 weighted images.^cHypointensity or rim-like pseudocapsule on the portal or equilibrium phases of dynamic MRI.^dSustained hyperintensity regardless of b value size on DWI.

value owing to the partial volume averaging effect with the background parenchyma. Third, although many haemangiomas and typical arteriportal shunts were excluded, a number of benign or pseudolesions seemed to be too small to validate them with 100% specificity as non-neoplastic lesions on DWI and dynamic MRI. Fourth, we did not consider the degree of cirrhosis, such as the Child–Pugh classification, and the degree of cirrhosis probably affected tumour enhancement on dynamic MRI and tumour signal intensity on DWI. Fifth, we did not compare the value of DWI with gadoxetic acid, which has been used for assessment of HCCs as a liver-specific contrast agent providing high sensitivity for small lesion detection [11, 33, 34]. However, the hypointensity on the hepatobiliary phase is not the result of true washout of contrast agent, and its specificity is still controversial in the diagnosis of HCCs. The value of gadoxetic acid imaging has yet to be considered in the recently updated diagnostic criteria of HCCs produced by the European Association for the Study of the Liver and the American Association for the Study of Liver Disease [1, 35].

Conclusion

Small arterial hypervascular lesions occasionally are a source of contention in the assessment of cirrhotic patients with high risk of HCC development. Compared with the washout appearance during dynamic imaging, DWI could provide more reliable information for the MRI assessment of small hypervascular HCCs in distinguishing them from atypical hypervascular benign or pseudolesions. DWI may considerably complement the early diagnosis of small hypervascular HCCs that do not display venous washout during gadolinium-enhanced dynamic imaging.

References

1. Bruix J, Sherman M, Llovet JM, Beaugrand M, Lencioni R, Burroughs AK, et al. Clinical management of hepatocellular carcinoma. Conclusions of the Barcelona-2000 EASL conference. *J Hepatol* 2001;35:421–30.
2. Bruix J, Sherman M. Practice Guidelines Committee, American Association for the Study of Liver Diseases. Management of hepatocellular carcinoma. *Hepatology* 2005;42:1208–36.
3. Yu JS, Lee JH, Chung JJ, Kim JH, Kim KW. Small hypervascular hepatocellular carcinoma: limited value of portal and delayed phases on dynamic magnetic resonance imaging. *Acta Radiol* 2008;49:735–43.
4. Nasu K, Kuroki Y, Nawano S, Kuroki S, Tsukamoto T, Yamamoto S, et al. Hepatic metastases: diffusion-weighted sensitivity-encoding versus SPIO-enhanced MR imaging. *Radiology* 2006;239:122–30.
5. Parikh T, Drew SJ, Lee VS, Wong S, Hecht EM, Babb JS, et al. Focal liver lesion detection and characterization with diffusion-weighted MR imaging: comparison with standard breath-hold T_2 -weighted imaging. *Radiology* 2008;246: 812–21.
6. Zech CJ, Herrmann KA, Dietrich O, Horger W, Reiser MF, Schoenberg SO. Black-blood diffusion-weighted EPI acquisition of the liver with parallel imaging: comparison with a standard T_2 -weighted sequence for detection of liver lesions. *Invest Radiol* 2008;43:261–6.
7. Xu PJ, Yan FH, Wang JH, Lin J, Ji Y. Added value of breathhold diffusion-weighted MRI in detection of small

- hepatocellular carcinoma lesions compared with dynamic contrast-enhanced MRI alone using receiver operating characteristic curve analysis. *J Magn Reson Imaging* 2009;29:341–9.
8. Yu JS, Chung JJ, Kim JH, Cho ES, Kim DJ, Ahn JH, et al. Detection of small intrahepatic metastases of hepatocellular carcinomas using diffusion-weighted imaging: comparison with conventional dynamic MRI. *Magn Reson Imaging* 2011;29:985–92.
 9. Piana G, Trinquart L, Meskine N, Barrau V, Beers BV, Vilgrain V. New MR imaging criteria with a diffusion-weighted sequence for the diagnosis of hepatocellular carcinoma in chronic liver diseases. *J Hepatol* 2011;55:126–32.
 10. Nishie A, Tajima T, Ishigami K, Ushijima Y, Okamoto D, Hirakawa M, et al. Detection of hepatocellular carcinoma (HCC) using super paramagnetic iron oxide (SPIO)-enhanced MRI: added value of diffusion-weighted imaging (DWI). *J Magn Reson Imaging* 2010;31:373–82.
 11. Kim JE, Kim SH, Lee SJ, Rhim H. Hypervascular hepatocellular carcinoma 1 cm or smaller in patients with chronic liver disease: characterization with gadoxetic acid-enhanced MRI that includes diffusion-weighted imaging. *AJR Am J Roentgenol* 2011;196:758–65.
 12. Semelka RC, Brown ED, Ascher SM, Patt RH, Bagley AS, Li W, et al. Hepatic hemangiomas: a multi-institutional study of appearance on T_2 -weighted and serial gadolinium-enhanced gradient-echo MR images. *Radiology* 1994;192:401–6.
 13. Yu JS, Kim KW, Jeong MG, Lee JT, Yoo HS. Nontumorous hepatic arterial-portal venous shunts: MR imaging findings. *Radiology* 2000;217:750–6.
 14. Earls JP, Rofsky NM, DeCorato DR, Krinsky GA, Weinreb JC. Hepatic arterial-phase dynamic gadolinium-enhanced MR imaging: optimization with a test examination and a power injector. *Radiology* 1997;202:268–73.
 15. Lim JH, Choi D, Park CK, Lee WJ, Lim HK. Encapsulated hepatocellular carcinoma: CT-pathologic correlations. *Eur Radiol* 2006;16:2326–33.
 16. Farmer DG, Rosove MH, Shaked A, Busuttil RW. Current treatment modalities for hepatocellular carcinoma. *Ann Surg* 1994;219:236–47.
 17. Digumarthy SR, Sahani DV, Saini S. MRI in detection of hepatocellular carcinoma (HCC). *Cancer Imaging* 2005;5:20–4.
 18. Semelka RC, Martin DR, Balci C, Lance T. Focal hepatic lesions: comparison of dual phase CT and multisequence multiplanar MR imaging including dynamic gadolinium enhancement. *J Magn Reson Imaging* 2001;13:397–401.
 19. Sugahara T, Korogi Y, Kochi M, Ikushima I, Shigematu Y, Hirai T, et al. Usefulness of diffusion-weighted MRI with echoplanar technique in the evaluation of cellularity in gliomas. *J Magn Reson Imaging* 1999;9:53–60.
 20. Burdette JH, Elster AD, Ricci PE. Acute cerebral infarction: quantification of spin-density and T_2 shine-through phenomena on diffusion-weighted MR images. *Radiology* 1999;212:333–9.
 21. Naganawa S, Sato C, Nakamura T, Kumada H, Ishigaki T, Miura S, et al. Diffusion-weighted images of the liver: comparison of tumor detection before and after contrast enhancement with superparamagnetic iron oxide. *J Magn Reson Imaging* 2005;21:836–40.
 22. Koike N, Cho A, Nasu K, Seto K, Nagaya S, Ohshima Y, et al. Role of diffusion-weighted magnetic resonance imaging in the differential diagnosis of focal hepatic lesions. *World J Gastroenterol* 2009;15:5805–12.
 23. 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;173:393–8.
 24. Taouli B, Tolia AJ, Losada M, Babb JS, Chan ES, Bannan MA, et al. Diffusion-weighted MRI for quantification of liver fibrosis: preliminary experience. *AJR Am J Roentgenol* 2007;189:799–806.
 25. Kwee TC, Takahara T, Ochiai R, Nievelstein RA, Luijten PR. Diffusion-weighted wholebody imaging with background body signal suppression (DWIBS): features and potential applications in oncology. *Eur Radiol* 2008;18:1937–52.
 26. Taouli B, Sandberg A, Stemmer A, Parikh T, Wong S, Xu J, et al. Diffusion-weighted imaging of the liver: comparison of navigator triggered and breathhold acquisitions. *J Magn Reson Imaging* 2009;30:561–8.
 27. Kim YK, Lee YH, Kim CS, Han YM. Added diagnostic value of T_2 -weighted MR imaging to gadolinium-enhanced three-dimensional dynamic MR imaging for the detection of small hepatocellular carcinomas. *Eur J Radiol* 2008;67:304–10.
 28. van den Bos IC, Hussain SM, Dwarkasing RS, Hop WC, Zondervan PE, de Man RA, et al. MR imaging of hepatocellular carcinoma: relationship between lesion size and imaging findings, including signal intensity and dynamic enhancement patterns. *J Magn Reson Imaging* 2007;26:1548–55.
 29. Shimizu A, Ito K, Koike S, Fujita T, Shimizu K, Matsunaga N. Cirrhosis or chronic hepatitis: evaluation of small (≤ 2 -cm) early-enhancing hepatic lesions with serial contrast-enhanced dynamic MR imaging. *Radiology* 2003;226:550–5.
 30. Holland AE, Hecht EM, Hahn WY, Kim DC, Babb JS, Lee VS, et al. Importance of small (≤ 20 -mm) enhancing lesions seen only during the hepatic arterial phase at MR imaging of the cirrhotic liver: evaluation and comparison with whole explanted liver. *Radiology* 2005;237:938–44.
 31. Kanematsu M, Kondo H, Semelka RC, Matsuo M, Goshima S, Hoshi H, et al. Early-enhancing non-neoplastic lesions on gadolinium-enhanced MRI of the liver. *Clin Radiol* 2003;58:778–86.
 32. Baert AL, Marchal GJ, Wilms GE, Usewils RM, Fever JM. A comparative study angiography and dynamic computed tomography in liver angioma. A report of 15 cases. *J Comput Tomogr* 1982;6:245–55.
 33. Motosugi U, Ichikawa T, Sou H, Sano K, Tominaga L, Muhi A, et al. Distinguishing hypervascular pseudolesions of the liver from hypervascular hepatocellular carcinomas with gadoxetic acid-enhanced MR imaging. *Radiology* 2010;256:151–8.
 34. Golfieri R, Renzulli M, Lucidi V, Corcioni B, Trevisani F, Bolondi L. Contribution of the hepatobiliary phase of Gd-EOB-DTPA-enhanced MRI to dynamic MRI in the detection of hypovascular small (≤ 2 cm) HCC in cirrhosis. *Eur Radiol* 2011;21:1233–42.
 35. Bruix J, Sherman M. Management of hepatocellular carcinoma: an update. *Hepatology* 2011;53:1020–2.