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Experience with use of multi-phase transmission in 3-tesla magnetic resonance imaging of the upper abdomen

Tsutomu Kato, M.D., Ph.D.

General Manager of Department of Radiology, Sumitomo Besshi Hospital

INTRODUCTION

A major problem with 3-tesla magnetic resonance imaging (3T-MRI) has been that when imaging the torso, which is a one of the thickest parts of the body, the higher resonance frequencies do not achieve homogeneity in the deeper regions of the body, resulting in irregular and inconsistent imaging. However, the development of multi-phase transmission has made it possible to obtain distortion-free, homogeneous images. This paper is about the clinical experience of multi-phase transmission with the "Vantage Titan™ 3T". This is a technique which uses two radio-frequency amplifiers, and modulates the power supply using four points, which decreases B_1 non-homogeneity. This happens immediately upon moving the patient inside the MRI aperture which results in major improvement in image quality.

MULTI-PHASE TRANSMISSION OVERCOMES THE DISADVANTAGES NORMALLY PRESENT DURING 3T EXAMINATIONS OF THE TORSO

With 3T-MRI, imaging is most difficult with obese patients, but multi-phase transmission enables reasonably clear images to be obtained (Fig. 1). In addition, Enhanced Fat-Free Imaging, which is a new fat-suppression method, enables consistent fat-suppression efficacy using two fat-suppression pulses, with the difference between signals generated by the first pulse being reduced by the second pulse. Simultaneous use of Enhanced Fat-Free Imaging with Multi-phase transmit technology makes it possible to achieve more homogeneous images (Fig. 2).

The presence of ascites is another cause of irregular and inconsistent imaging, but multi-phase transmission has made homogeneous imaging possible. In addition, fat suppression by the spectral attenuated-inversion recovery method (SPAIR) has made clear separation feasible, even with respect to subcutaneous water, etc. This method also makes imaging with very little distortion possible, even when items such as metal surgical staples or titanium screws are present.

As described above, multi-phase transmission enables assurance of a high degree of magnetic field homogeneity. It also makes it possible to overcome the effects of obesity, large ascites volume, internal metallic objects, etc., which present problems for 3T-MRI.

CHARACTERISTICS OF 3T-MRI TISSUE CONTRAST

• T1-weighted imaging

According to the research carried out by de Bazelaire *et al.* on the differences between relaxation times with abdominal MRI at 3 and 1.5 tesla (T)[1)], in the cases of the liver, spleen and pancreas the T1 value at 3 T was markedly extended, whereas in the case of the muscles there was no difference between the relaxation times with 1.5 and 3 T, as a result of which there was a decrease in the differences between the T1 values at 3 T in the liver, pancreas and muscle. In this context, the relationships between the liver, pancreas and muscle with T1-weighted imaging were verified. Figures 3 to 5 show the following images, respectively, obtained by the gradient-echo method: two-dimensional (2D), in-phase/out-of-phase images; T1-weighted, 2D, in-phase, fat-suppressed images; and T1-weighted, three-dimensional (3D), spoiled, fat-suppressed images. These images show that there is a tendency, with T1-weighted, fat-suppressed imaging, for the liver, pancreas and muscle to show signals of similar strength, although there are differences to some degree. The principal diseases that result in weak signals from the liver, and result in the pancreas appearing relatively blank, include fatty liver, and hepatic cirrhosis.

Next, with respect to the level of contrast enhancement, gadolinium-based relaxation agents, which reduce the T1 value, have high efficacy, and it is therefore expected that high-resolution, contrast-enhanced, T1-weighted images will be obtained. Figure 6 shows a comparison of contrast enhancement in a hepatocellular carcinoma patient, with gadolinium ethoxybenzyl diethylenetriaminepentaacetic acid (Gd-EOB-DTPA), at 1.5 and 3 T, with a favorable contrast-to-noise ratio being maintained with 3 T, even with high-resolution imaging, and heterogeneity being shown in the liver parenchyma with hepatic cirrhosis.

Tissue contrast enhancement using manganese chloride tetrahydrate (Bothdel), with T1-weighted imaging using undiluted solution, shows a high-signal solution, and artifacts are therefore readily generated, and dilution is essential. However, if the solution is diluted too much, signals are generated by T2-weighted imaging. Therefore, three-fold dilution is optimal.

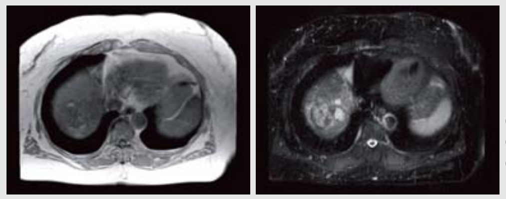
• T2-weighted imaging

T2-weighted imaging of the upper abdomen is carried out using the fast-spin echo (FSE) and single-shot fast-spin echo (FASE) methods. With respect to the T2 value, there are no differences in relaxation times with 1.5 and 3 T[1)], so, although the T1 value is extended at 3 T, it is expected that, by extending the repetition time and/or echo time more than with 1.5 T, images with a similar degree of T2-weighting can be expected.

Due to the high level of noise at 3 T, it is thought to be preferable to use FASE, but, as shown for a hepatocellular carcinoma patient in Figure 7, the contrast achieved with FASE is sometimes insufficient. On the other hand, with diseases such as hepatic cysts and hepatic hemangioma, with FSE there is little difference between the signals. In addition, with FASE there are cases of markedly strong signals being given by cysts (Fig. 8). At the present time, it is therefore considered preferable for imaging to be carried out with both FSE and FASE.

With respect to application of these methods to the pancreas, Figure 9 shows a case of pancreatic head cancer. Although the difference between FSE and FASE with pancreatic parenchymal cancer is minor, with FASE there is less image blurring, and the main pancreatic duct can be more readily observed, so FASE is considered to give more diagnostic power in the case of pancreatic diseases. In addition,

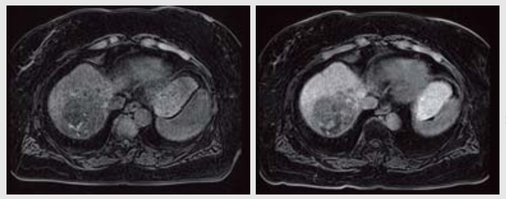
a b



2D-GR (TR/TE=160/2.3 FA=90) | FASE (TR/TE=21000/120 ET=88) (SPAIR method)

Fig. 1: Images of obese hepatocellular carcinoma patient obtained using multi-phase transmission

a b



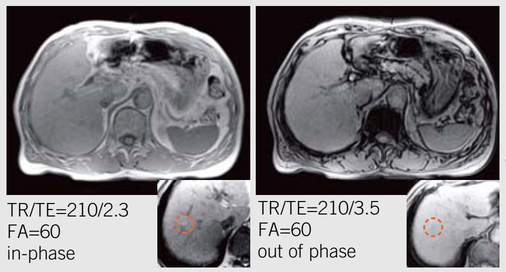
Before Gd-EOB-DTPA contrast enhancement | Contrast-enhanced using Gd-EOB-DTPA: Hepatocyte phase

Spoiled 3D-GR (TR/TE=3.7/1.3 FA=9)

Fig. 2: Enhanced Fat-Free used simultaneously with Multi-phase transmit (same patient as in Fig. 1)

a: Before Gd-EOB-DTPA contrast enhancement;
b: Contrast-enhanced using Gd-EOB-DTPA: Hepatocyte phase.
Fat suppression is excellent, and highly homogeneous images were achieved.

a b

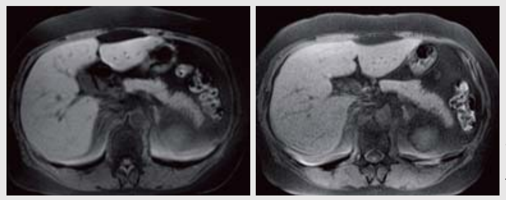


TR/TE=210/2.3 FA=60 in-phase | TR/TE=210/3.5 FA=60 out of phase

Fig. 3: 2D, gradient-echo, in-phase/out-of-phase images

Hepatocellular carcinoma, containing fat. Whether in phase or out of phase, there were no marked differences between the signals from the liver, pancreas and muscle.

a: 1.5 T b: 3 T

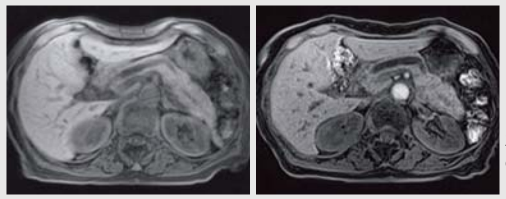


TR/TE=218/5.3 FA=90 5 mm thick 256 × 256 | TR/TE=159.4 /2.3 FA=50 5 mm thick 512 × 512

Fig. 4: T1-weighted, 2D, gradient-echo, in-phase, fat-suppressed images

With the 3T 2D method, there was little difference between the T1 values in the liver, pancreas and muscle, and therefore also little difference between the signals. Pathologies in which the pancreatic signal weakens are chronic inflammation, cysts, and tumors.

a: 1.5 T b: 3 T



VIBE method TR/TE=4.3/1.8 FA=12 5 mm thick 256 × 256 | Quick 3D's method TR/TE=3.7/1.3 FA=12 2 mm thick 512 × 512

Fig. 5: T1-weighted, 3D, spoiled, gradient-echo, fat-suppressed images

Even with the 3T, 3D, gradient-echo method, there was little difference between the signals in the liver, pancreas and muscle, except that the signal in the muscle tended to be rather weak.

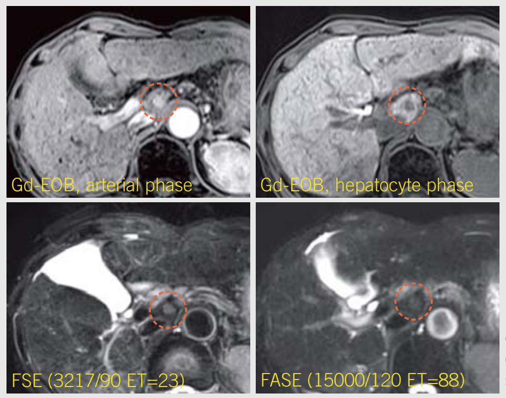
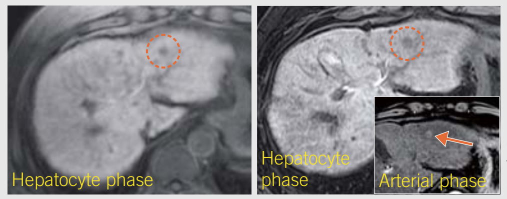


Fig. 7: Case of hepatocellular carcinoma showing early-phase dense staining

The tumor contrast with FASE is less clear than with FSE.

a: 1.5 T b: 3 T

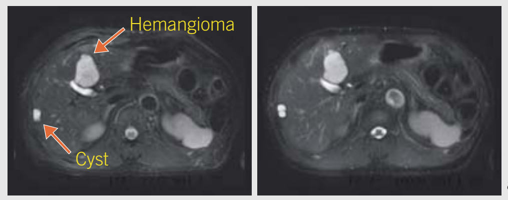


1.5 × 1.3 × 5.0 (mm) | 0.6 × 0.6 × 2.0 (mm)

Fig. 6: Gd-EOB-DTPA contrast enhancement with hepatocellular carcinoma

At 3 T, a favorable contrast-to-noise ratio was maintained even with high-resolution imaging, and heterogeneity was shown in the liver parenchyma with hepatic cirrhosis. A small area of early-stage dense staining was detected, as shown by the arrow.

a b



FSE TR/TE=2272/90 ET=23 | FASE TR/TE=16000/80 ET=80

Fig. 8: T2-weighted images of hepatic cyst and hemangioma

With FSE, only weak signals are given by hepatic cysts and hepatic hemangiomas, whereas with FASE markedly strong signals are given by cysts.

with FASE-based magnetic-resonance cholangiopancreatography, no clear difference in contrast is found between 1.5 and 3 T.

• Diffusion-weighted imaging
Even with diffusion-weighted imaging, numerous lesions show strong signals at 3 T, but the signals in non-lesional areas show more tendency to be retained than with 1.5 T, making it difficult to show the appropriate b-value at that time. There are also sometimes marked distortions, and further research is needed.

HIGH-RESOLUTION CHARACTERISTICS OF 3T-MRI

At 3 T, with a voxel size of 0.6 × 0.6 × 2.0 mm, extremely high-resolution images can be achieved (Fig. 10), and high precision and detail can be achieved with contrast-enhanced imaging, even with magnetic-resonance cholangiopancreatography. On the other hand, due to the great increase in the number of images made, when these techniques are used on a routine basis, there are problems with respect to the requirements for image interpretation time, and the capacity of the picture archiving and communication system (PACS). The approaches to overcoming these difficulties and applying the techniques to clinical use are issues to be evaluated in the future.
If, due to the high signal-to-noise ratio, resolution equal to computed tomography is achieved, it is expected that this technique will be applied to the diagnosis, staging assessment, etc., of pancreatic cancer, which requires accurate anatomic information. However, this remains to be verified.

NON-CONTRAST-ENHANCED MAGNETIC-RESONANCE ANGIOGRAPHY

Non-contrast-enhanced magnetic-resonance angiography is frequently used for the upper abdomen. True steady-state free precession (TrueSSFP) with 3D imaging enables clear images of the common bile duct, biliary system, hepatic veins, portal vein, etc., to be obtained, and is highly useful. The range of applications is expected to increase further in future with inclusion of the time-spatial labeling inversion pulse (Time-SLIP) method.

CONCLUSIONS

In the case of 3T-MRI for the upper abdomen, although there is room for improvement with respect to diffusion-weighted imaging, non-contrast-enhanced magnetic-resonance angiography, etc., the development of multi-phase transmission has meant that the technique can be used in routine and regular examinations. An issue that remains to be determined is how and to what degree high-resolution imaging will be applied clinically.

References
1) de Bazelaire, CMJ, et al.: MR imaging relaxation times of abdominal and pelvic tissues measured *in vivo* at 3.0 T: Preliminary results, *Radiology*, 230: 652-659, 2004.

Tsutomu Kato, M.D., Ph.D.
From 1983: Dept. of Radiology, Kansai Medical University. From 1994: Dept. of Radiology, Kagawa Medical University. Since 1998: Sumitomo Besshi Hospital. Currently: Director, Sumitomo Besshi Hospital; General Manager, Dept. of Radiology (Sumitomo Besshi Hospital); part-time lecturer, Kansai Medical University; specialist physician (diagnosis), Japan Radiological Society.

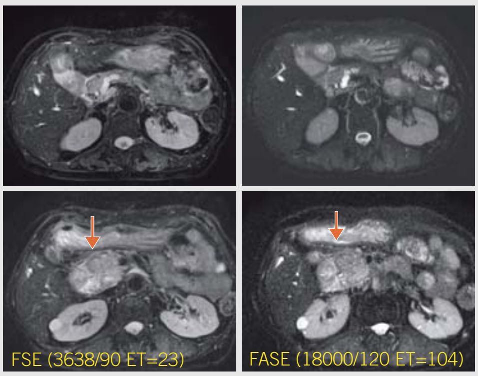
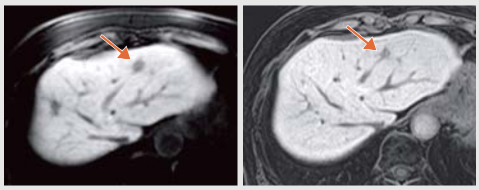


Fig. 9: Case of pancreatic head cancer

With parenchymal pancreatic cancer, there tends to be little difference between FSE and FASE. Verification is needed. With FASE, there is less image blurring, and the main pancreatic duct can be more readily observed.

a: 1.5 T b: 3 T



1.5 × 1.3 × 5.0 (mm) 0.6 × 0.6 × 2.0 (mm)

The tumor margins are clearly shown with 3 T.

Fig. 10: Case of hepatocellular carcinoma: High-resolution imaging with Gd-EOB, hepatocyte phase

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