How to reduce so-called ringing artifacts in Primovist-enhanced MR imaging

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Introduction

Primovist (gadoxetic acid; Gd-EOB-DTPA)-enhanced MR imaging has been used for the diagnosis of focal hepatic lesions worldwide. However, except for spatial misregistration due to breath-hold failure, empirically 10-15% of cases suffer from so-called "ringing artifacts" during the acquisition of the arterial phase. These artifacts aggravate the detection and characterization of focal hepatic lesions (Fig. 1). To avoid the problem, we first simulated the artifacts in various conditions with a custom-made software, and then applied the countermeasures deduced from the analysis to the daily practice of Primovist-enhanced MR imaging.

Methods

Computer Simulation: To analyze the ringing artifacts, N.H. programmed a simulation software on the personal computer (Windows Vista). This program takes an arbitrarily drawn schematic image, typically a human anatomy, and the MR scan parameters for a 3D fast imaging as inputs. It then segments the image into parts by color. After it prompts the operator to supply a time-intensity curve or constant value for each part, it starts calculating simulated object image at every sampling points in time (Fig.2a), does 2D Fourier transform to create corresponding k-space images (Fig.2b), picks up the relevant lines from them to produce a simulated "raw data" (Fig.2c), and finally reconstructs it back to a simulated image (Fig.2d). The changes in the time-intensity curves and scan and data acquisition parameters result in different Fig.2a and Fig.2b images. The choice of phase-encoding scheme, either sequential or centric, heavily influences the Fig.2c image.

Clinical MR imaging: Primovist-enhanced MR imaging was performed at 1.5 T scanners (GE, Signa HDx). All patients underwent precontrast baseline and Primovist-enhanced dynamic 3D-GRE (LAVA), followed by T2W, DWI, and Primovist-enhanced hepatocyte phase (15 min after injection). In the clinical MR imaging, we compared imaging artifacts among various imaging conditions using a 4-point scale by visual inspections (4: no artifact, 3: mild, 2: moderate, 1: severe) under the consensus of two experienced radiologists.

Results

Computer Simulation: The simulation shows that the cause of ringing artifacts is two-fold. The one is the steep change in gadolinium concentration during the arterial phase (Fig.3). When the gadolinium concentration is almost constant (3 min & 20 min), few artifacts occur. The worst case scenario is the premature imaging timing with centric phase order, missing out on the gadolinium enhancement at the crucial low-frequency views (Fig.3, 27 sec). The other cause is the mismatch in frequency and phase encoding direction matrices, or truncation artifact. In the comparison between rectangular (256x128) and square (256x256) matrices size, ringing artifacts dramatically decreased in 256x256 (Fig 4a). Between lengthier and shorter scanning time, shorter one brought less ringing artifacts (Fig. 4b). Similarly, between centric and sequential view ordering, or between rapid and slow infusion rate, sequential view ordering or slow infusion rate produced less artifacts (Fig. 4c).

Clinical MR imaging: In comparison between rectangular (320x192) and square (256x256) matrices for 40 consecutive patients each, MR images with square matrices showed significantly less artifacts in the arterial ($P<0.05$), portal ($P<0.01$), and hepatocyte phase ($P<0.05$; Table 1). For 320x192 matrix, hepatocyte phase showed significantly less artifact than arterial ($P<0.05$) and portal phase ($P<0.01$). Between rapid (mean 3 ml/sec) and slow (mean 1.5 ml/sec) infusion rate for 70 consecutive patients each, slow infusion rate brought significantly less artifacts ($P<0.05$; Table 2).

Discussion and Conclusion

Ringing artifacts are derived from truncation artifacts and phase ghost from organs and vessels. Truncation artifacts are caused by the mismatch of phase and frequency encoding steps [1]. Phase ghosts are caused by steep change of gadolinium concentration during the k-space data acquisition, particularly noted in the arterial phase [2]. These phenomena are emphasized with rapid infusion rate, lengthier scanning time, and centric view ordering. In the arterial phase of dynamic MR imaging, the change of gadolinium concentration is inevitable and this artifact might be a fateful event of dynamic MR imaging. Approved dose of Primovist (0.025 mmol/kg) is one fourth of conventional gadolinium compounds; therefore, the short length of Primovist bolus results in steeper change of gadolinium concentration than conventional gadolinium compounds. By selecting square matrix size, slower infusion rate, shorter scanning time, and sequential view ordering, ringing artifacts could be reduced.

References 1. Levy LM, et al. Radiology 166: 479, 1988. 2. Spraggins TA. Magn Reson Med 31: 320, 1994.

Table 1 Comparison between rectangular & square matrix

matrix	arterial	portal	hepatocyte
320x192	3.3±0.1	3.2±0.1	3.6±0.1
256x256	3.7±0.1	3.7±0.1	3.8±0.1

Table 2 Comparison between rapid & slow infusion rate

	2 sec infusion (N=70)	4 sec infusion (N=70)
dose	6.1±1.1 ml (3 ml/sec)	6.1±1.2 ml (1.5 ml/sec)
rank 4	36	46
rank 3	23	21
rank 2	9	3
rank 1	2	0

Fig. 1 Ringing artifacts

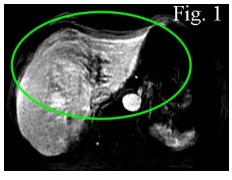

Fig.2 Simulation software

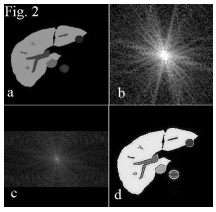

Fig.3 Relationship between scan timing after Primovist injection and artifacts

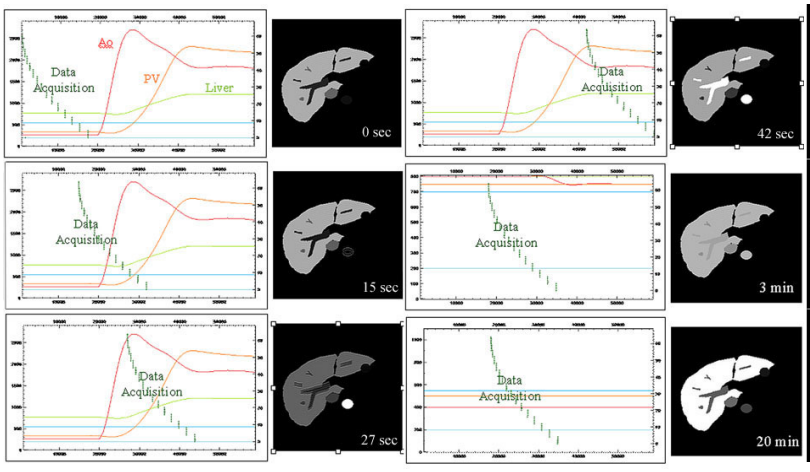

Fig.4 Various parameters and artifacts