Evaluation of simultaneous saline injection methods in Gd-EOB-DTPA-enhanced magnetic resonance imaging for reducing truncation artifacts

Poster No.: C-0824
Congress: ECR 2012
Type: Scientific Exhibit
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Keywords: Liver, MR, Contrast agent-intravenous, Artifacts
DOI: 10.1594/ecr2012/C-0824

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Purpose

In gadolinium ethoxybenzyl diethylenetriaminepentaacetic acid (Gd-EOB-DTPA) -enhanced magnetic resonance imaging (MRI), truncation artifacts appear on arterial phase images because the rapid bolus injection causes a signal amplitude change when sampling at high spatial frequencies in $k$-space [1-3]. To suppress these artifacts, it is necessary to control the abrupt flow of contrast agent into the liver during image acquisition (Fig. 1 on page 2).

In a previous study, dilution of Gd-EOB-DTPA with saline was reported to lead to a reduction in truncation artifacts [4]. Dilution of Gd-EOB-DTPA lengthens the duration of the contrast agent injection. Consequently, there is a decrease in truncation artifacts because signal amplitude, which is inhomogeneous during $k$-space filling, is suppressed by the dilution of Gd-EOB-DTPA.

This method, however, may increase the risk of contamination during preparation of the contrast agent [5]. Therefore, simultaneous injection of the contrast agent and saline using a commercially available mechanical injector is described here as a method for reducing truncation artifacts. This simultaneous injection method obtains the dilution effect without diluting the contrast agent in advance.

The aim of this study was to evaluate the effect of simultaneous injection of Gd-EOB-DTPA and saline on reducing truncation artifacts in MR images.

Images for this section:
Figure 1

- The feature of Gd-EOB-DTPA.
  - The volume of Gd-EOB-DTPA injected is small.
  - Higher T1-relaxivity.

- Truncation artifacts appear on arterial phase images because the rapid bolus injection causes a signal amplitude change when sampling at high spatial frequencies in $k$-space.

- It is necessary to control the abrupt flow of contrast agent into the liver during image acquisition.

Fig. 1: Figure 1. The feature and problem in Gd-EOB-DTPA-enhanced MRI.
Methods and Materials

Materials:
MR scanner: 1.5-T Signa HDx (GE Medical Systems, Milwaukee, WI).
Receive coil: 12-element body array coil (GE Medical Systems)
Power injector: Sonic Shot GX (Nemoto kyorindo Co., Ltd., Tokyo, Japan)

Patients:
In total, 120 patients (85 men, 35 women; mean age, 63.3 ± 14.1 years; range, 21-88 years) suspected to having liver disease (Fig. 2 on page 6) underwent dynamic Gd-EOB-DTPA-enhanced MRI.

Sequence parameters:
Dynamic T1-weighted images were acquired using a fat-suppressed three-dimensional fast spoiled- gradient recalled echo sequence [liver acceleration volume acquisition (LAVA)]. Figure 3 shows imaging parameters for LAVA (Fig. 3 on page 6).

Gd-EOB-DTPA injection methods: (Fig. 4 on page 7)
Gd-EOB-DTPA at a dose of 0.025 mmol/kg was administered intravenously in the cubital or cephalic vein.
Patients were divided into 4 groups according to the different injections administered.

#Conventional injection method:
Gd-EOB-DTPA was injected intravenously as a bolus at the rate of 2 mL/s using a power injector. After the administration of Gd-EOB-DTPA, 20-mL of saline was injected at 2 mL/s to flush the line.

#Half-simultaneous injection method:
Gd-EOB-DTPA and saline (at half the dose of Gd-EOB-DTPA) were simultaneously administered intravenously at the same rate (1 mL/s). A 20-mL volume of saline was administered at 2 mL/s to flush line.

#Equal-simultaneous injection method:
Gd-EOB-DTPA and saline (in equal doses) were injected simultaneously at 1 mL/s. A 20-mL volume of saline was administered at 2 mL/s to flush the line.

**Double-simultaneous injection method:**

Gd-EOB-DTPA and saline (at double the dose of Gd-EOB-DTPA) were injected simultaneously at 1 mL/s. A 20-mL volume of saline was administered at 2 mL/s to flush the line.

To determine the optimal scan delay for the arterial phase, an automated bolus detection algorithm (MR SmartPrep, GE Medical Systems) was used. Contrast agent was injected into the abdominal aorta (upper surface of the diaphragm). When signal intensity increased above threshold, images were acquired with a scanning delay of 10 s.

**Evaluation of imaging:**

**Quantitative analysis:**

The signal intensity (SI) change ratio for the abdominal aorta was calculated as

\[
\text{SI change ratio} = \frac{\text{SI}_{\text{pre}} - \text{SI}_{\text{post}}}{\text{SI}_{\text{pre}}}
\]

where \( \text{SI}_{\text{pre}} \) = signal intensity measured precontrast and \( \text{SI}_{\text{post}} \) = signal intensity measured postcontrast.

The contrast ratio (CR) change ratio in the liver-to-skeletal muscle was calculated as

\[
\text{CR change ratio} = \frac{\text{CR}_{\text{post}}}{\text{CR}_{\text{pre}}}
\]

\([\text{CR} = \frac{\text{SI of liver (right or left lobe)}}{\text{SI of skeletal muscle}}]\), where

\( \text{CR}_{\text{pre}} \) = contrast ration measured precontrast and

\( \text{CR}_{\text{post}} \) = contrast ration measured postcontrast.

The region of interest (ROI) was the abdominal aorta at the level of the celiac trunk, right and left hepatic lobes, and skeletal muscle on corresponding slices from all patients (Fig. 5 on page 8).

**Qualitative analysis:**

The quality of the images obtained after each injection method was evaluated on a 4-point scale (4 = excellent, 3 = good, 2 = poor, and 1 = non-diagnosis) by 1 radiologist and 2 radiographers, who were blinded to rate of injection administered.
The appearance and degree of truncation artifacts from vessels and liver margins were evaluated. Sample images corresponding to each score are shown in Fig.6 (Fig. 6 on page 9).

**Statistical analysis:**

The SI change ratio and the CR change ratio for the 4 injection methods were compared using analysis of variance, followed by Scheffe test, and are expressed as mean±SD. For the comparison of image quality between the 4 injection methods, the Kruskal-Wallis test, followed by the Mann-Whitney test, was employed. A p value ≤0.05 was considered statistically significant. Statistical analyses were performed using the software packages SPSS Version 19.0 (SPSS Inc., Chicago, IL).

**Images for this section:**

**Figure 2**

Patients: 120 patients (male: 85, women: 35)
Mean age: 63.3 ± 14.1 years (range: 21-88 years)

Patients diseases
- Hepatocellular carcinoma (n = 30)
- Metastases (n = 19)
  - colon cancer = 10, stomach cancer = 4
  - breast cancer = 1, cholangiocarcinoma = 1
  - renal cell carcinoma = 1, pancreatic cancer = 2
- Hemangioma (n = 10)
- Cyst (n = 14)
- Focal nodular hyperplasia (n = 7)
- Not particular (n = 40)

**Fig. 2:** Figure 2. Diseases found in patients diagnosed with Gd-EOB-DTPA-enhanced MRI.
Figure 3

- Pulse sequence: LAVA
  Repetition time (TR)/Echo time (TE), 3.0/1.4 ms;
  Flip angle (FA), 12°;
  Band width (BW), ±83.33 kHz;
  Number of signals acquired (NSA), 1;
  Field of view (FOV), 40 × 40 cm;
  Matrix, 288 × 192;
  Slice thickness, 5 mm;
  Array spatial sensitivity encoding technique (ASSET) reduction factor, 2;
  Image-acquisition time, 16 s;
  k-space trajectory, phase-locked loop, centric order.

Fig. 3: Figure 3. Sequence parameters for liver acceleration volume acquisition (LAVA).
Figure 4

- Conventional injection method
- Half-simultaneous injection method
- Equal-simultaneous injection method
- Double-simultaneous injection method

: Gd-EOB-DTPA  : Saline solution (simultaneous injection)
: Saline solution (injection for flushing)

**Fig. 4:** Figure 4. Scheme of each injection method for the Gd-EOB-DTPA-enhanced MRI.
Figure 5: Figure 5. Example of Region of interest (ROI) placed in abdominal aorta (upper surface of celiac artery), right and left hepatic lobe, and skeletal muscle, for calculating SI change ratio and CR change ratio. The ROIs were drawn in the same location for each patient. In the liver parenchyma, ROI were placed in homogeneous areas free of large blood vessels and tumors.
**Figure 6**: Figure 6. Examples of image quality evaluation. The images quality of each injection methods were evaluated using a 4 point scale (4 = excellent, 3 = good, 2 = poor, and 1 = non diagnosis). The evaluation followed appearance degree of truncation artifact from vessels and liver margins.
Results

**Quantitative analysis:**

Figure 7 shows the SI change ratio and the CR change ratio (Fig. 7 on page 11).

Although the SI change ratios for the abdominal aorta for the images obtained after the conventional injection method were higher than those obtained after the simultaneous injection methods, no significant differences in the mean SI change ratio between 4 groups were found. In addition, no significant differences in the right and left hepatic lobe and the changes ratio of skeletal muscles CR among the 4 groups were found.

**Qualitative analysis:**

Figure 8 shows the image quality attained with the 4 injection methods (Fig. 8 on page 12). Image quality with the simultaneous injection method was significantly higher than that with the conventional injection method \((p < 0.05)\). The proportion of excellent- and good-quality images to the total number of images evaluated was 43.3% (39/90) with the conventional injection method, 77.8% (70/90) with the half-simultaneous injection method, 85.6% (77/90) with the equal-simultaneous injection method, and 91.1% (82/90) with the double-simultaneous injection method.

**Images for this section:**
Table 1

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<td>Equal-simultaneous</td>
<td>Double-simultaneous</td>
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<td>SI change ratio</td>
<td>5.66 ± 1.78</td>
<td>5.94 ± 1.69</td>
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<td>6.60 ± 1.93</td>
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<td>CR change ratio</td>
<td>1.02 ± 0.11</td>
<td>1.05 ± 0.20</td>
<td>1.12 ± 0.27</td>
<td>1.04 ± 0.13</td>
<td>n.s.</td>
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<tr>
<td>(Right lobe)</td>
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<tr>
<td>CR change ratio</td>
<td>1.03 ± 0.09</td>
<td>1.06 ± 0.16</td>
<td>1.11 ± 0.26</td>
<td>1.07 ± 0.12</td>
<td>n.s.</td>
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<tr>
<td>(Left lobe)</td>
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Fig. 7: Results of quantitative analysis in the 4 protocols.
**Fig. 7**

![Bar chart showing quality of images acquired after different injection methods.](chart.png)

**Fig. 8:** Figure 7. Quality of images acquired after the different injection methods.
Conclusion

The results indicate that simultaneous injection resulted in improved image quality without affecting the change ratios of the liver- muscle CR and SI changes of the abdominal aorta.

With simultaneous injection, a high injection rate can be achieved even though the contrast agent is being injected at a low rate because the total rate combines both the contrast agent and saline. Furthermore, it is possible to prolong injection duration. As a result, we believe that the degree of truncation artifacts decreased because appropriate scan timing of the arterial phase was facilitated by the longer of injection duration.

Furthermore, diluted Gd-EOB-DTPA is able to obtain a high signal because Gd-EOB-DTPA exhibits a higher T1-relaxivity. Therefore, we believe that no significant differences in the CR change ratio for the right and left hepatic lobes and skeletal muscles nor in the SI change ratios for the abdominal aorta between conventional and simultaneous injection were found.

In simultaneous injection, the possibility of infection need not be considered because preparation of a combination is not necessary. In addition, this method is possible in any institution with an injector device. Therefore, clinical application is safe and simple possible.

In conclusion, this study demonstrated that simultaneous injection of Gd-EOB-DTPA and saline, which avoids dilution of the contrast agent in advance, decreases truncation artifacts and is safe for clinical application.

References


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