Fat quantification with dual energy CT: Comparison of 3-material decomposition dual energy CT analysis and MRI in phantoms of varying fat-iodine contrast content

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Authors: S. Takahashi¹, T. Itoh², H. Niikawa³, H. Yamamoto³, K. Sugimura¹; ¹Kobe/JP, ²Tokyo/JP, ³Osaka/JP
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Purpose

Background

Nonalcoholic fatty liver disease (NAFLD), which is now the major cause of chronic liver disease, shows association with the metabolic disorders, such as diabetes mellitus, obesity, hyperlipidemia, and insulin resistance (1, 2). As NAFLD may progress to nonalcoholic steatohepatitis or cirrhosis, early detection of the disorder is advocated.

Liver biopsy is the gold standard for assessing the severity of hepatic fat deposition (3). However, liver biopsy is an invasive procedure with a potential risk of life-threatening complication and may cause sampling error due to heterogeneous fat deposition in the liver. Therefore, liver biopsy would not be optimal procedure for monitoring of disease progression or response to treatment. Thus, non-invasive hepatic imaging techniques are now receiving increasing attention in detection and quantification of fat in the liver.

Ultrasound, computed tomography, and magnetic resonance (MR) imaging and spectroscopy have been used for quantification of fat in the liver (4). Among these techniques MR spectroscopy has been used as the gold-standard to separate fat and water resonances and provide fat fraction assessment in researches (5, 6). Although MR spectroscopy is promising technique for the accurate assessment of fat deposition, it is a time consuming, operator and subject dependent technique with a limited spatial resolution, as well as limited availability, which prevent wide progression of MR spectroscopy in the evaluation of hepatic steatosis in clinical practices. Recent studies have shown that in-phase and out-of-phase gradient echo imaging could be used to rapidly estimate the liver fat content (7).

In clinical practice CT is widely applied for the evaluation of chronic hepatic diseases and neoplasms. The degree of fat deposition might be estimated with hepatic attenuation measured with Hounsfield units (HU). In practice, however, the HU values could be affected with a degree of iron deposition in the liver, and the conventional CT could only provide limited contrast resolution for the soft-tissue on unenhanced study. Thus, most investigators prefer to evaluate fat content with comparing the hepatic attenuation to an internal standard devoid of fat, such as the spleen on unenhanced CT (8). Either the measurement of the absolute hepatic attenuation or the difference in attenuation between the liver and spleen is reported to detect only moderate or severe hepatic steatosis (greater than 30% on histology) (9). This evaluation is, of course, available only on non-contrast studies.

Recent studies with dual-source CT (DSCT) show that dual-energy analysis with DSCT can characterize tissue component even on post-contrast study (10). Therefore, it is
expected that dual-energy CT imaging may detect and evaluate moderate or less hepatic steatosis even on the post-contrast study.

**Purpose**

The objective of our phantom study was to compare the ability of dual-energy CT with MRI for quantification of fat content with and without contrast medium.

**Methods and Materials**

**Phantoms**

Phantoms of varying fat-water or fat-CM content were constructed adding the surfactant to water or diluted CM (50 or 100HU) as the methods by Bernard et al. (11). Six fat-water phantoms were created with following composition; olive oil only, water, and four emulsions containing 10, 20, 30 and 40% amount of olive oil. Fat-CM phantoms were also made with the same concentration of fat for CM of 50 and 100HU. The gels remained stable and creaming did not occur during the time of imaging.

**CT imaging**

Each set of fat-water, or fat-CM of 50 or 100HU phantoms was placed in the middle of 20-cm water bath with placing their long axis parallel to the z-axis of the scanner. Dual energy CT data were acquired with a dual-source 64-detector row CT imager (SOMATOM Definition; Siemens Medical Solutions) that two x-ray tubes and detector arrays were arranged in a perpendicular configuration. The scans were obtained using a tube voltage of 80 and 140kVp pair with a tube current of 330 and 60mAs, respectively, pitch of 0.60, 1.0-second gantry rotation period, 512×512 pixel matrix, a minimum field of view of 65mm, and detector collimation of 14×1.2mm. Pair of 5-millimeter thick images for both 80kVp and 140kVp were reconstructed with 1-mm increment using dual-energy Kernel of D20. Simultaneous data acquisition with perpendicularly arranged two sets of x-ray tube and detector allowed obtaining images of identical slice location, timing and resolution with different x-ray energy of 80 and 140kVp.

**MR imaging**

The phantoms were also scanned with 1.5T MR scanner (Signa HD, GE Healthcare, Milwaukee, Wis). Each phantom was placed with its long axis parallel to the z-axis of the scanner. After obtaining orthogonal T2-weighted single-shot fast spin echo images, 16-mm-thick single slice coronal dual-echo gradient echo image was obtained with two-dimensional spoiled gradient recalled acquisition in the steady state (SPGR) sequence.
on page 7 using following parameters: repetition time /echo time of 300 msec /2.25 and 4.2 msec, 20° flip angle, bandwidth of 391 Hz/pixel, 256×256 pixel matrix, and 100-mm field of view. The coronal slice was chosen to cover entire phantom with single slice.

**Dual-energy CT analysis**

Dual-energy analysis was conducted on originally developed dual-energy imaging analysis software performed in the Matlab environment (Matlab, version 7.10; MathWorks, Natick, Mass). Prior to the analysis a three-dimensional noise reduction filter was applied to each set of images for continuous slices. First, iodine contribution was eliminated by 3-material decomposition. Then, a lipid magnitude map on page 6 was calculated based on negative shift of CT values on 80kV image using water and olive oil as references of 0% and 100% lipid, respectively. Circular region of interest (ROI) was drawn to measure lipid magnitude of each phantom.

**Fat fraction analysis**

Rectangular ROI was drawn to cover entire area of each phantom to measure the signal intensity (SI) on in-phase images (SI_{IP}) and on out-of-phase images (SI_{OP}) with an exact matching location. Then, fat fraction (FF) on page 8 was calculated for each phantom with following formula:

$$FF = \frac{SI_{IP} - SI_{OP}}{SI_{IP} + SI_{IP}} \times 100 \, \%.$$

**Image analysis**

Lipid magnitude evaluated with dual-energy CT was compared to FF of MR imaging. Linear regression analysis was used for evaluating the relationship between FF of MRI and lipid magnitude with dual-energy CT, with FF as the independent variable and lipid magnitude as the dependent variable. Statistical analyses were performed by using computer software package (GraphPad Prism for Macintosh 4.0c; GraphPad Software, San Diego, CA) and a two-tailed P value of less than .05 was considered statistically significant.

**Images for this section:**
**Fig. 1:** CT image fat-water phantoms with 10, 20, 30, 40, and 100% of olive oil scanned at 80kVp
Fig. 2: CT image fat-water phantoms with 10, 20, 30, 40, and 100% of olive oil scanned at 140kvP
Fig. 3: Lipid magnitude map for fat-water phantoms with 10, 20, 30, 40, and 100% of olive oil
<table>
<thead>
<tr>
<th>Out-of-phase</th>
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<td>10% oil</td>
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**Fig. 4:** Dual-echo (in-phase and out-of-phase) gradient echo images for phantoms of varying fat-water content of 10, 20, 30 and 40%.
Fig. 5: Fat fraction map calculated with MR images.
Results

Lipid magnitude maps were successfully created for fat-water on page 10, fat-CM of 50HU on page 12, and fat-CM of 100HU on page 14 phantoms.

On the regression analysis, lipid magnitude with dual-energy CT showed excellent correlation with FF of MRI for each phantom ($R^2 = .99$).

The slope and the intercept were 1.01 (95% confidence intervals: 0.88 to 1.13) and -3.8% (-9.65 to 2.05) for fat-water phantom on page 11, 0.97 (0.85 to 1.07) and -4.9% (-10.34 to 0.37) for fat-CM of 50HU phantom on page 13, 0.94 (0.81 to 1.07) and -4.4% (-10.5 to 1.68) for fat-CM of 100HU phantom on page 15.

Images for this section:
**Fig. 1:** Lipid magnitude map for fat-water phantoms with 10, 20, 30, 40, and 100% of olive oil
Fig. 2: Correlation between fat fraction calculated with MRI and lipid magnitude evaluated with dual-energy CT for fat-water phantom
Fig. 3: Lipid magnitude map for fat-CM of 50HU phantoms with 10, 20, 30, 40, and 100% of olive oil
**Fig. 4:** Correlation between fat fraction calculated with MRI and lipid magnitude evaluated with dual-energy CT for fat-CM of 50HU phantom
Fig. 5: Lipid magnitude map for fat-CM of 100HU phantoms with 10, 20, 30, 40, and 100% of olive oil
**Fig. 6:** Correlation between fat fraction calculated with MRI and lipid magnitude evaluated with dual-energy CT for fat-CM of 100HU phantom.
Conclusion

Dual-energy analysis with DSCT could quantify fat content either in water or diluted CM as same as MRI.

References

Personal Information

Satoru Takahashi MD, PhD
Department of Radiology, Kobe University Hospital
staka@med.kobe-u.ac.jp