Original Investigation

Clinical Application of Dual-Energy Spectral Computed Tomography in Detecting Cholesterol Gallstones From Surrounding Bile

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Rationale and Objective: This study aimed to investigate the clinical value of spectral computed tomography (CT) in the detection of cholesterol gallstones from surrounding bile.

Materials and Methods: This study was approved by the institutional review board. The unenhanced spectral CT data of 24 patients who had surgically confirmed cholesterol gallstones were analyzed. Lipid concentrations and CT numbers were measured from fat-based material decomposition image and virtual monochromatic image sets (40–140 keV), respectively. The difference in lipid concentration and CT number between cholesterol gallstones and the surrounding bile were statistically analyzed. Receiver operating characteristic analysis was applied to determine the diagnostic accuracy of using lipid concentration to differentiate cholesterol gallstones from bile.

Results: Cholesterol gallstones were bright on fat-based material decomposition images yielding a 92% detection rate (22 of 24). The lipid concentrations (552.65 ± 262.36 mg/mL), CT number at 40 keV (–31.57 ± 16.88 HU) and 140 keV (24.30 ± 5.85 HU) for the cholesterol gallstones were significantly different from those of bile (–13.94 ± 105.12 mg/mL, 12.99 ± 9.39 HU and 6.19 ± 4.97 HU, respectively). Using 182.59 mg/mL as the threshold value for lipid concentration, one could obtain sensitivity of 95.5% and specificity of 100% with accuracy of 0.994 for differentiating cholesterol gallstones from bile.

Conclusions: Virtual monochromatic spectral CT images at 40 keV and 140 keV provide significant CT number differences between cholesterol gallstones and the surrounding bile. Spectral CT provides an excellent detection rate for cholesterol gallstones.

Key Words: Tomography; X-ray computed; dual-energy CT; material decomposition; cholesterol gallstones.

INTRODUCTION

Gallstones are a common disease in the gallbladder with an incidence rate of about 10% and occur mostly in middle-aged women. There are three common gallstones: cholesterol, bile pigment, and mixed stone (1). Cholesterol stone is the main type of gallstone, and is iso- or slightly hypoattenuating relative to bile. The experiment by Brakel et al. (2) proved that the computed tomography (CT) value of the stones negatively correlated with cholesterol content and positively with calcium content. The cholesterol stone has CT attenuation similar to the surrounding bile under the normal X-ray or CT examination and is often difficult to detect. Cholesterol stones are therefore often referred to as negative stones and are easily missed in conventional CT using CT number alone (3). The recently introduced dual-energy spectral CT imaging uses information from two different energy spectrums to provide additional material density and effective atomic number information for different materials such as different stones (4), as well as a set of virtual monochromatic images at different photon energy levels. This multiparameter (photon energy-dependent CT number and material density value) approach should improve the separation of materials that have similar CT attenuation value using polychromatic energy beams but different intrinsic material densities such as the cholesterol gallstone and bile. The purpose of this study was to investigate the clinical value of dual-energy spectral CT imaging in the detection of cholesterol gallstones.

MATERIALS AND METHODS

I. General Information

This retrospective study was approved by the institutional review board. The authors retrospectively analyzed the CT

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imaging data of 24 patients from July 2013 to June 2014 who underwent unenhanced spectral CT scans for upper abdominal pain in our hospital. Because cholesterol gallstones are easily missed in the conventional CT imaging, the study population was limited to patients who had only this type of stone confirmed by surgery. These patients included 10 men and 14 women with mean age of 48 years (32–67 years), mean body mass index (BMI) of 24.40 ± 4.11 kg/m^2, no history of biliary surgery, and no fatty diet in the week before the CT examination.

II. CT Scan Technique

Patients were asked to drink 700–1000 mL of warm water as negative contrast before the CT scan. The unenhanced CT scan was performed on a Discovery CT750 HD scanner (GE Healthcare, Waukesha, WI) with the single-tube, dual-energy (80 kVp and 140 kVp) fast-switching spectral imaging mode. Patient BMI-dependent gemstone spectral imaging (GSI) presets (GSI-36: slim patients with BMI < 20 kg/m^2; GSI-40: standard size patients with 20 < BMI < 24 kg/m^2; GSI-1: overweight patients with 24 < BMI < 28 kg/m^2; and GSI-27: obese patients with BMI > 28 kg/m^2) were used which yielded an average volumetric CT dose index (CTDIvol) of 11.53 ± 2.94 mGy. This value was smaller than the typical dose of 15.43 mGy in conventional abdominal CT scans on a normal adult patient with BMI of 25 kg/m^2 in our hospital. Other spectral CT scan parameters included body bowtie with 40-mm collimator width and spiral scan with pitch of 1.375:1. All patients were scanned feet-first in supine position. The scan range was from the top of the diaphragm to the low edge of the liver, which contained the whole gallbladder.

III. Image Analysis

Both the material decomposition image using fat and water as basis material pair and 11 sets of virtual monochromatic images with energy levels from 40 keV to 140 keV (in 10 keV interval) were generated from the unenhanced spectral CT scan. The image thickness was 1.25 mm. These image sets were transferred to an advanced workstation (AW4.6, GE Medical Systems, Milwaukee, WI) for image analysis and data measurement using the GSI viewer (GE Medical Systems).

The fat-based material decomposition image and virtual monochromatic images were displayed side by side, where the fat-based material decomposition images were used to identify and locate the cholesterol gallstones. Two radiologists with more than 5 years of experience in abdominal CT imaging who did not read the clinical cases and were not aware of the surgical findings determined the location and size of the cholesterol gallstone in consensus with the material decomposition and virtual monochromatic images. Circular or oval region of interest (ROI) was placed in the center and covered about one-half to two-thirds of the gallstone on the material decomposition image. An ROI of the same size was used for the surrounding bile. The ROI on the material decomposition image was propagated to all monochromatic image sets for CT number and standard deviation measurements.

Lipid concentrations for gallstone and bile were determined from the fat-based material decomposition images; their CT numbers and standard deviations were measured, and contrast-to-noise ratio (CNR) for gallstones was calculated from the virtual monochromatic image sets with energy levels of 40–140 keV. CNR was defined using the following expression: $CNR = (ROI_{gallstone} - ROI_{bile})/SD$, where $ROI_{gallstone}$ and ROI_{bile} are the CT numbers for the gallstone and bile, respectively, and SD represents the standard deviation in bile. To avoid overexposure of patients, single-energy conventional 120-kVp CT scans were not taken. Because of having muscle CT number similar to the conventional 120-kVp abdominal imaging, the 70-keV virtual monochromatic images in spectral CT were used to simulate the results of conventional CT scans for comparison (5). This is different from the dual-tube, dual-energy imaging where two images with different average energy levels (generated from 80 kVp and 140 kVp tube voltages, for example) were weighted to produce images with energy level similar to the conventional 120-kVp imaging.

IV. Statistical Analysis

Statistical analysis was performed using SPSS 17.0 (SPSS Inc., Chicago, IL). The differences in lipid concentration and CT number between the gallstone and the surrounding bile were statistically analyzed. Because sample sizes were small, the Wilcoxon signed-rank test was used for the paired samples. A P value <.05 was considered statistically significant. Receiver operating characteristic (ROC) analysis was applied to determine the diagnostic accuracy of using lipid concentration to differentiate cholesterol gallstones from bile. True-positive cases were defined as those in which cholesterol gallstone was correctly identified. False-positive cases were defined as those in which bile was misdiagnosed as cholesterol gallstone. The diagnostic accuracy was determined by calculating the area under the reader-specific ROC curve. Sensitivity and specificity for differentiating cholesterol gallstones from the surrounding bile were calculated.

RESULTS

The diameters of the cholesterol gallstones were determined in surgery to be 11.23 ± 5.3 mm (3–23 mm). Five of the stones were at the bottom, eight in the middle, and eleven near the neck of gallbladder. The cholesterol gallstones appeared to be bright on the dark background of bile in the fat-based material decomposition image (Fig 1a), and 22 of 24 gallstones were identified. Two gallstones were missed by the spectral CT imaging. These two stones were all smaller than 5 mm in diameter and were located near the neck of the gallbladder. As a comparison, no cholesterol gallstones were identified using the conventional CT number difference criteria on the 70-keV images (Fig 1d).