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Iodine removal in intravenous dual-energy CT-cholangiography: Is virtual non-enhanced imaging effective to replace true non-enhanced imaging?

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ABSTRACT

Purpose: To evaluate whether virtual non-enhanced imaging (VNI) is effective to replace true non-enhanced imaging (TNI) applying iodine removal in intravenous dual-energy CT-cholangiography.
Materials and Methods: From April 2009 until February 2010, fifteen potential donors for living-related liver transplantation (mean age 37.6 ± 10.8 years) were included. Potential donors underwent a two-phase CT-examination of the liver. The first phase consisted of a single-energy non-enhanced CT-acquisition that provided TNI. After administration of hepatobiliary contrast agent, the second phase was performed as a dual-energy cholangiographic CT-acquisition. This provided VNI. Objective image quality (attenuation values [bile ducts and liver parenchyma] and contrast-to-noise ratio) and subjective overall image quality (1 – excellent; 5 – non diagnostic) were evaluated. Effective radiation dose was compared.
Results: For TNI and VNI, attenuation values for bile ducts were 16.8 ± 11.2 HU and 5.5 ± 17.0 HU ($p < 0.05$) and for liver parenchyma 55.3 ± 8.4 HU and 58.1 ± 10.6 HU (n.s.). For TNI and VNI, contrast-to-noise ratio was 2.6 ± 0.6 HU and 6.9 ± 2.1 HU ($p < 0.001$). For VNI, subjective overall image quality was 1 in ten datasets, 2 in four datasets and 3 in one dataset. Effective radiation dose for the dual-energy cholangiographic CT-acquisition was 3.6 ± 0.9mSv and for two-phase single-energy CT-cholangiography 5.1 ± 1.3mSv ($p < 0.001$).
Conclusion: In this study on iodine removal in intravenous dual-energy CT-cholangiography, subjective image quality is equivalent, contrast-to-noise ratio is improved and effective radiation dose is reduced when VNI is performed. The differences between TNI and VNI with respect to attenuation values seem to have limited clinical relevance and therefore we consider VNI as effective to replace TNI.

1. Introduction

According to the clinical indication, standard CT-examinations of the abdomen include non-enhanced and contrast-enhanced acquisitions in different phases (e.g. arterial and porto-venous) [1]. Non-enhanced images are important to identify calcifications and fat [2]. They are the basis for quantification of contrast-uptake in abdominal masses. Non-enhanced acquisitions are important to delineate artificial materials (e.g. clips and drainages). They are essential in patients suspected of having active hemorrhage for the identification of the bleeding site [3]. CT-cholangiography with administration of a hepatobiliary contrast agent opacifies the biliary system [4]. Comparable to abdominal CT-examinations with administration of an extracellular contrast agent, non-enhanced images before infusion of a hepatobiliary contrast agent are essential to make correct diagnoses of the biliary system (e.g. stones, leaks, hemobilia, and tumors) [5,6]. Modern CT-systems provide the possibility of dual-energy imaging. Independent of the technical realization (either as dual-source scanners with two X-ray tubes and detectors or by rapid switching of the tube voltage of a single-tube scanner), a dual-energy CT-acquisition is performed as acquisition of two different raw datasets [2]. The doubled photon spectra information allows superb differentiation of iodine due to its high atomic number [7]. Dual-energy post-processing on the basis of the three-material decomposition theory (soft tissue versus fat versus iodine) can remove iodine from contrast-enhanced images resulting in virtual non-enhanced images [8]. Virtual non-enhanced imaging (VNI) derived

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from contrast-enhanced dual-energy CT-acquisitions has proven efficacy in multiple clinical investigations [2,9,10]. However, all published data covers extracellular contrast agents. In contrast, our study evaluates the feasibility of VNI after administration of an intracellular, hepatobiliary contrast agent. The purpose was to evaluate whether VNI is effective to replace true non-enhanced imaging (TNI) applying iodine removal in intravenous dual-energy CT-cholangiography.

2. Materials and methods

2.1. Patients

From April 2009 until February 2010, dual-energy CT image data of fifteen potential donors for living-related liver transplantation (nine women and six men) were acquired. Main clinical data included a mean age of 34.4 ± 9.6 years (23–48 years), a mean weight of 73.4 ± 9.1 kg (range 50.1–84.0 kg), a mean height of 176.2 ± 7.3 cm (range 169–189 cm), a mean body mass index (BMI) of 25.3 ± 3.3 kg/m^2 (range 22.4–29.8 kg/m^2), a mean bilirubin level of 0.7 ± 0.2 mg/dl (range 0.3–1.3 mg/dl), a mean pseudocholine esterase level of 9.1 ± 2.2 U/l (range 5.3–13.9 U/l), a mean albumine level of 44.7 ± 3.2 g/l (range 39.1–47.8 g/l) and a mean thromboplastin time of 99.6 ± 12.1 s (range 72.0–119.6 s). None of the potential donors had a history of adverse reactions to iodinated contrast agents, renal insufficiency (creatinine >1.5 mg/dl), elevated serum bilirubin levels (>1.5 mg/dl) or hepatobiliary surgery. All potential donors underwent preoperative evaluation of the biliary system applying intravenous dual-energy CT-cholangiography for which they gave written informed consent. In our institution, CT-cholangiography constitutes one of the final diagnostic steps in the evaluation of potential donors for living-related liver transplantation. The prospective study at hand was approved by the Institutional Review Board and compliant with the requirements of the Health Insurance Portability and Accountability Act.

2.2. CT-examination

All potential donors received standard premedication with 400 mg cimetidine (Ranitic®, Hexal, Holzkirchen, Germany) and 4 mg clemastinhydrogenfumarat (Tavegil®, Novartis, Munich, Germany) to prevent adverse contrast agent reactions. The examinations were performed with the same 64-slice multi-row detector dual-source CT-scanner (Somatom Definition DS, Siemens Medical Solutions, Forchheim, Germany). The liver was studied with a two-phase protocol. The first phase consisted of a single-energy non-enhanced CT-acquisition (64 × 0.6 mm collimation; 120 kVp tube potential; quality reference tube current of 240 mAs; 0.5 s gantry rotation time; pitch 0.55) providing TNI. Subsequently, we performed slow and continuous infusion of the hepatobiliary contrast agent (100 ml of meglumine iotroxate, Biliscopin®; Bayer Schering, Berlin, Germany) using an automated infusion pump with an injection rate of 150 ml/h [11]. Five minutes after completion of the contrast agent infusion, the second phase was performed as a dual-energy cholangiographic CT-acquisition (64 × 0.6 mm collimation; 140 kVp and 80 kVp tube potential; quality reference tube current of 96 mAs (140 kVp) and 404 mAs (80 kVp); 0.5 s gantry rotation time; pitch 0.55) [5]. The potential donors were off-center positioned in the gantry to center the liver within the smaller field-of-measurement of the second detector ($Ø_{FOV(B)}$ = 26.0 cm). The scan lengths of the single-energy non-enhanced CT-acquisition and of the dual-energy cholangiographic CT-acquisition were selected to be identical. The dual-energy dataset provided VNI and true enhanced imaging (TEI).

2.3. Image reconstruction

For abdominal dual-energy CT, recommended collimation is 14 mm × 1.2 mm [12]. In our study, we selected a thinner collimation to reduce partial volume effects and to increase spatial resolution as much as possible in order to increase the visualization of the tiny high-order bile ducts. For the single-energy non-enhanced CT-acquisition and for the dual-energy cholangiographic CT-acquisition, overlapping axial images of 0.75 mm slice thickness were reconstructed with an increment of 0.4 mm. Further image parameters included a soft tissue window with a center of 56 HU and a width of 342 HU. Medium soft body kernels were used for image reconstructions of the single-energy non-enhanced CT-acquisitions (B20f) and dual-energy cholangiographic CT-acquisitions (B20 and D20). TEI were reconstructed using both raw datasets with the recommended weighting ratio (30% 140 kVp, 70% 80 kVp) [2]. VNI was performed on the basis of the dual-energy application ("Liver-VNC®", Siemens Medical Solutions, Forchheim, Germany) [2]. To obtain VNI from the dual-energy cholangiographic CT-acquisition, the basic presets included an iodine image overlay of 0% (yielding "no" iodine images).

2.4. Image analysis – general considerations

Axial images were evaluated independently by two different pairs of radiologists (one and six years experience of abdominal imaging as well as four and ten years experience of abdominal imaging) on a picture archiving and communication system work station (GE Centricity 4.1, GE Healthcare, Barrington, USA). TNI, VNI and TEI were evaluated side-by-side. The information of the TEI was important for definition of the bile ducts and the renal pelvic system. Image analysis included an objective and a subjective part. Objective image analysis was performed blinded to the subjective image analysis by the identical pairs of radiologists. For objective image analysis, regions of interest (ROIs) in TNI, VNI and TEI had to be placed in corresponding positions. Since the z-positions of the anatomic structures were different in TNI and VNI/TEI, manual correction after co-registration was necessary. Therefore, anatomical landmarks (e.g. portal vein, hilar fat, liver veins and hepatic ligaments) were used.

2.5. Objective image quality

2.5.1. Attenuation values

For TNI, VNI and TEI, attenuation values (in Hounsfield units [HU]) were determined for bile ducts, gallbladder, liver, kidney, spleen, psoas muscle and aorta [2,9]. Size, shape and position of the ROIs were kept constant between the three different datasets. For bile ducts, the attenuation values were calculated as mean of four attenuation measurements (one in the right and one in the left intrahepatic main duct as well as two in the common duct) in circular ROIs with an area of 4–6 mm^2. For gallbladder, liver, kidney, spleen, psoas muscle and aorta, the attenuation values were calculated as mean values of three attenuation measurements in circular ROIs with an area of 1–3 cm^2.

2.5.2. Image noise, signal-to-noise ratio and contrast-to-noise ratio

For TNI, VNI and TEI, image-noise was defined for bile ducts, gallbladder, liver, kidney, spleen, psoas muscle and aorta as the mean standard deviation (SD) of the particular attenuation measurements. For TNI, VNI and TEI, duct-to-liver signal-to-noise ratio