64-Slice multidetector row CT angiography of the abdomen: comparison of low versus high concentration iodinated contrast media in a porcine model

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Objective: In this study we aimed to assess the image quality and degree of vascular enhancement using low-concentration contrast media (LCCM) (300 mg I ml⁻¹) and high-concentration contrast media (HCCM) (370 mg I ml⁻¹) on 64-slice multidetector row CT (MDCT) abdominal CT angiography (CTA). In addition, we aimed to study the feasibility of using HCCM with a reduced total iodine dose.

Methods: CTA of the abdomen on a 64-slice MDCT was performed on 15 anaesthetised pigs. Study pigs were divided into three groups of five each based on the iodine concentration and dose received: Group A (LCCM; 300 mg I ml⁻¹), Group B (HCCM; 370 mg I ml⁻¹) and Group C HCCM with 20% less iodine dose. The total iodine injected was kept constant (600 mg kg⁻¹) in Groups A and B. Qualitative and quantitative analyses were performed to study and compare each group for image quality, visibility of the branch order of the superior mesenteric artery (SMA), artefacts, degree of enhancement in the aorta and main stem arteries and uniformity of enhancement in the aorta. Groups were compared using the analysis of variance test.

Results: The image quality of 64-slice MDCT angiography was excellent with a mean score of 4.63 and confident visualisation of the third to fifth order branches of the SMA in all groups. Group B demonstrated superior vascular enhancement, as compared with Groups A and C ($p \leq 0.05$). Uniform aortic enhancement was achieved with the use of LCCM and HCCM with 20% less iodine dose.

Conclusion: 64-slice MDCT angiography of the abdomen was of excellent quality. HCCM improves contrast enhancement and overall CTA image quality and allows the iodine dose to be reduced.

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CT angiography (CTA) has rapidly emerged as a non-invasive imaging modality of choice to evaluate vasculature and vascular conditions in the abdomen [1–4]. Multidetector row CT (MDCT) has played a crucial role in the widespread acceptance of CTA as a non-invasive alternative to catheter angiography. Technical advances with the addition of more detector rows have significantly improved the spatial resolution and scanning speed of MDCT. CTA is evolving to adapt to these changes in MDCT technology. A marked reduction in scan duration with the newer 64-slice MDCT requires optimisation of scan timing to catch the bolus of enhancement for vascular and multiphasic organ imaging. Therefore, contrast administration strategies and scanning protocols need to be optimised either by increasing the rate of contrast injection or through the use of contrast media (CM) with a higher iodine concentration to adapt to a shorter scan duration. Increasing the rate of CM injection is limited, as it requires a relatively large-bore intravenous cannula for injection and could potentially increase the risk of extravasation [5]. By contrast, increasing the iodine

concentration in CM not only improves contrast enhancement by increasing iodine flux, but could also help to reduce the volume of CM; the use of reduced volumes is highly desirable to match the shorter acquisition times on 16-slice and higher MDCT [6]. Use of high-concentration CM (HCCM) has been shown to provide superior vascular enhancement as compared with low-concentration CM (LCCM) on either 4- or 16-slice MDCT [7–11].

In this study, we assessed the performance of abdominal CTA on 64-slice MDCT and compared the degree of enhancement and image quality using LCCM (300 mg I ml⁻¹) with HCCM (370 mg I ml⁻¹) in a porcine model. In addition, the potential of reducing the contrast volume or total iodine dose with the use of HCCM for CTA was assessed and compared with a regular dose of LCCM and HCCM.

Methods and materials

Study design

In this prospective experimental study, an initial approval from the subcommittee for research on animals was obtained that was in compliance with the federal regulation

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for the use of laboratory animals. A total of 15 pigs of Yorkshire breed (male:female 8:7) with an average age of 3.7 months (range 3.1–4.2 months) and an average weight of 47.8 kg (range 45–50.3 kg) were selected for the study. CTA was performed over a 6 month duration from November 2004 to April 2005.

Contrast media injection strategies

A non-ionic, low osmolar contrast material (Iopamidol) of either LCCM (300 mg I ml⁻¹) or HCCM (370 mg I ml⁻¹) from the same vendor (Isovue, Bracco diagnostics, Inc, Princeton, NJ) was used for this study. Study pigs were divided into three groups of five each based on the iodine concentration in CM and iodine dose used: Group A ($n=5$) received LCCM with a total iodine dose of 600 mg I kg⁻¹ body weight; Group B ($n=5$) received HCCM with a total iodine dose of 600 mg I kg⁻¹ body weight; and Group C ($n=5$) received the HCCM with a total iodine dose of 480 mg I kg⁻¹ body weight (*i.e.* 20% less iodine dose than in Groups A and B). The demographics and CM protocol used in the different groups are described in Tables 1 and 2.

Animal preparation

Pigs were kept on nil orally for 8 h and were pre-anaesthetised by intravenous administration of Telazol or Xylazine (Parke-Davis, Morris Plains, NJ) followed by endotracheal intubation and administration of isoflurane anaesthesia (1.5–3.0%) along with oxygen (3.0 l min⁻¹). Continuous monitoring of the pigs during the entire procedure was performed using a pulse oxymeter.

CT angiography technique

A 64-slice MDCT (SOMATOM Sensation 64, Siemens Medical Solutions, Forchheim, Germany) was used for this study. An 18 G intravenous cannula was placed in one of the ear lobe veins and the anaesthetised pig was placed in a supine position on the CT table. Non-enhanced axial images of the abdomen and pelvis were acquired initially using a detector collimation of 0.6 × 64 mm, a reconstructed slice thickness of 2.5 mm and a rotation time of 1 s.

Test bolus

To determine an optimal time for triggering the arterial phase scanning, a test bolus of CM was injected at 4 ml s⁻¹ followed by saline flush at 4 ml s⁻¹ using a dual-barrel injector (Empower CTA, E-Z-EM Inc, Lake Success, NY); a low-dose (80 kV, 20 mA) CT scan was acquired at a static table position at the level of the

domes of the diaphragm. The test bolus comprised 10% of the total calculated volume of CM used for CTA. The time delay between CM injection and initiation of scanning was determined by calculating the time to peak enhancement interval measured by placing the region of interest (ROI) within the upper abdominal aorta in the dynamic data set.

CT angiography

The calculated volume of CM was then injected at 4 ml s⁻¹ again followed by a saline flush at 4 ml s. The volume of injected saline was 25% of the volume of CM injected (contrast:saline 4:1). Arterial-phase scanning was performed using a detector collimation of 0.6 × 64 mm, reconstructed slice thickness of 0.75 mm, rotation time of 0.33 s, table feed of 38.4 mm rotation⁻¹, 120 kV and 250 mA. Scans were performed from the domes of the diaphragm to the symphysis pubis. The scans were obtained in free breathing by maintaining a steady respiratory rate of 10 respirations per minute in all pigs.

Image post-processing

Each data set obtained was post-processed on the scanner console (Leonardo workstation, Siemens Medical Solutions) by a single operator with 10 years experience. Images of the aorta and other abdominal arteries were reconstructed using three-dimensional and two-dimensional maximum-intensity projections (MIP) and volume-rendered (VR) reconstructions in coronal, sagittal and oblique planes, in addition to coronal multiplanar reformations. Three-dimensional thick MIP (2.5 mm thickness) and VR images of the aortiliac, mesenteric, hepatic and renal arteries in all three planes along with coronal reformations and axial image data were used for analysis. The imaging parameters and protocol were identical for all study pigs.

Qualitative data analysis

Qualitative analysis was performed by two fellowship-trained radiologists with 11 and 8 years experience, respectively, and each with a special interest in abdominal CTA. Readers were blinded to the details of contrast injection protocols used for each pig and images were reviewed on a picture archival and communication system (PACS) (IMPAX version 4.5, AGFA, Richmond, VA) workstation. Both axial and post-processed images were evaluated in consensus for overall image quality, artefacts and the number of visible branch orders from the superior mesenteric artery (SMA).

Image quality

Image quality was assessed on a subjective five-point scale based on the overall clarity of anatomic vascular

Table 1. Demographics

	Group A ($n=5$)	Group B ($n=5$)	Group C ($n=5$)
Sex (male:female)	3M:2F	3M:2F	2M:3F
Age, range (months)	3.6 (3.1–3.9)	3.8 (3.1–4.2)	3.7 (3.4–4)
Weight, range (kg)	48 (45.8–50)	47.6 (45–50)	48 (46.7–50.3)

Table 2. Contrast and injection protocol

	Group A	Group B	Group C
Iodine concentration (mg I ml ⁻¹)	300	370	370
Injection rate (ml s ⁻¹)	4	4	4
Saline flush (ml s ⁻¹) ^a	4	4	4
Volume of contrast for CTA, range (ml)	96 (92–100)	77 (73–81)	62 (61–65)
Iodine injection rate (mg I s ⁻¹)	1200	1400	1400
Total iodine dose (mg kg ⁻¹)	600	600	480
Scan delay, range (s)	12.8 (12–14)	13 (12–14)	12.2 (11–13)
Scan duration, range (s)	13.6 (12–14)	13.8 (13–14)	13 (12–14)

^aThe total volume of saline used was equivalent to 25% of the total volume of contrast used. CTA, CT angiography.

detail, the intensity of arterial enhancement and lack of venous enhancement. Quality was scored as follows: 1, unacceptable; 2, poor; 3, fair; 4, good; and 5, excellent.

Artefacts

In this evaluation, we focused on the effect on image quality caused by artefacts from motion as well as CTA technique. A scale of 1–3 was used to assign a score for the presence of artefacts. In contrast to the evaluation of image quality, a higher score indicated images with severe artefacts and poor quality: 1, artefacts absent; 2, artefacts mild but acceptable; and 3, severe and unacceptable artefacts.

Small visible arteries

The number of visible branching orders from the main SMA was counted by reviewing the axial and reconstructed images. This procedure was undertaken to assess the visualisation of small branches of the SMA on CTA with the use of different concentrations and iodine doses of CM.

Quantitative data analysis

Quantitative analysis was performed by a single investigator on a workstation (Advantage windows version 4.0, General Electric Medical Systems, Milwaukee, WI) to assess the degree of contrast enhancement in the aorta and the main stem branches and the uniformity of enhancement in the abdominal aorta.

Degree of enhancement

The degree of enhancement in the abdominal aorta and its main branches were assessed by measuring mean attenuation values (Hounsfield units; HU) on unenhanced and contrast-enhanced images. Mean attenuation values were obtained by placing a circular ROI in the abdominal aorta, proximal coeliac, superior mesenteric, and both renal and both common iliac arteries (<2 cm from origin) on both unenhanced and contrast-enhanced scans. ROI were carefully placed within the lumen of the arteries to include more than 90% cross-sectional area of the artery. The degree of enhancement in each artery was calculated by taking the absolute difference in attenuation values between the contrast-enhanced and unenhanced scans.

Uniformity of aortic enhancement

The uniformity of aortic enhancement was measured in a similar manner to the degree of enhancement by placing

an ROI in the aorta and measuring attenuation values. In this case, however, the ROI was placed on every 55th image (specifically, at every 1 s of scan data) of contrast-enhanced images from cranial to caudal end of the abdominal aorta. The absolute difference in attenuation values was obtained by subtracting contrast-enhanced HU values measured at multiple levels from attenuation values of the aorta on an unenhanced scan obtained at a single level (renal arteries).

Statistical analysis

Data were compiled in a database using Microsoft Access 2000 software (Microsoft Corporation, Redmond, WA) and statistical analysis was performed on MedCalc software (Version 7.6.0.0, Frank Schoonjans, Belgium). A one-way analysis of variance (ANOVA) was used to compare different groups and Student Newman–Keuls test was used for pairwise comparison on quantitative and qualitative analysis. The *p*-value was obtained for each comparison and a value ≤0.05 was considered to be of statistical significance. Mean interindividual enhancement variation within a group at different levels in the aorta and the difference between maximum and minimum enhancement was used to assess the uniformity of aortic enhancement.

Results

The CTA data from all study pigs (*n*=15) were evaluable and were included in the final analysis.

On qualitative analysis, the mean score on quality of CTA was superior in Group B with a score of 4.8, as compared with scores of 4.5 and 4.6 obtained in Groups A and C, respectively (Figure 1); however, there was no statistically significant difference (*p*=0.344) between the groups. On evaluation of artefacts in different groups, only one CTA study in Group B demonstrated mild motion artefact; the remaining 14 studies showed no obvious artefacts. Confident visualisation of fourth to fifth branching order (average of 4.4) from SMA was documented in Group B. In Groups A and C, third to fourth order branches were visualised with a mean score of 3.75 and 4, respectively, with no significant differences between the the groups (*p*=0.284) (Table 3).

On quantitative analysis, the mean degree of contrast enhancement was maximally achieved in Group B in the aorta and its main stem branches (Table 4). The arterial

Figure 1. Maximum-intensity projection (MIP) images of the abdominal aorta and its branches depict comparable quality with the use of (a) low-concentration contrast media (LCCM; Group A), (b) high-concentration contrast media (HCCM; Group B) and (c) HCCM with 20% less iodine dose (Group C). Similar visualisation of the fourth to fifth order branches of the superior mesenteric artery (SMA; arrow) together with uniform aortic enhancement from the cranial to caudal end on subjective comparison can be observed in each group.

enhancement in Group B was significantly higher than in Group A ($p \leq 0.05$). Similarly, the mean enhancement values were higher in Group C compared with Group A, but there was no statistical difference between the two groups on pairwise comparison. Compared with Group A, Groups B and C achieved an additional mean enhancement of 23.5% and 9%, respectively, for all arteries. There was no

significant difference in the magnitude of enhancement between Groups B and C.

The enhancement in the abdominal aorta from cranial to caudal end on CTA was found to be uniform in Groups A and C (Table 4) (Figure 2). By contrast, the interindividual enhancement variance of the aorta and the difference between maximum and minimum enhancement in the

Table 3. Qualitative analysis in different groups

	Group A	Group B	Group C	p-Value ^a
Quality of CTA on a scale of 1–5	4.5	4.8	4.6	0.344
Visualised branching order from SMA	3.75	4.4	4	0.284
Artefacts on a scale of 1–3	1	1.2	1	0.397

Values given in the table are the mean. CTA, CT angiography; SMA, superior mesenteric artery. ^aSignificant difference between groups on one way analysis of variance (ANOVA).

aorta were higher in Group B compared with Groups A and C ($p=0.001$). However, there was no significant difference between Groups A and C in the uniformity of aortic enhancement.

Discussion

The clinical success of CTA is based on precise synchronisation of image acquisition with optimal vascular enhancement [12]. In this study on the quality of CTA using 64-slice MDCT, we demonstrated a superior quality with confident visualisation of the third to fifth order branches of SMA using different concentrations of iodine in the CM. Advances in MDCT technology have transformed CTA into an excellent non-invasive imaging technique for most vascular territories [4]. The main advantages of MDCT are exceptionally fast scan times, high spatial resolution, increased anatomical coverage and the ability to generate high-quality reformations and three-dimensional renderings from raw data that can be reprocessed easily and quickly [12]. In addition, a substantial improvement in image quality can be achieved because narrower section profiles are employed with higher numbers of detectors [1]. 64-Slice MDCT offers 0.6-mm slice thickness, as compared with 0.75 mm on 16-slice MDCT, together with considerable improvements in spatial resolution, increased speed of volume coverage and a decrease in spiral artefacts owing to “z” flying spot technology [4]. Vessels measuring 0.1 to 0.3 mm in diameter can be visualised on 64-slice coronary CTA owing to its high spatial resolution. Similarly, in our study, we visualised third to fifth branching orders from SMA that were very small (Figure 1); however, the clinical

value of such information on small vessels is not known. In addition, 64-slice MDCT for CTA might be beneficial by avoiding venous contamination owing to its rapid acquisition of images. Although initial results of 64-slice coronary angiography for the evaluation of coronary stenosis seem quite promising compared with 16-slice MDCT, the potential use of 64-slice CTA of the abdomen is, to our knowledge, not yet published [4, 13, 14].

MDCT scanning speed can vary substantially based on the type of scanner, the acquisition parameters and the vascular territory of interest. The goal is to achieve an adequate degree of contrast enhancement in addition to the proper image acquisition. Often, injection strategies for CTA are categorised according to the acquisition time: long or short. A recent study by Napoli et al [1] demonstrated that biphasic administration of contrast is useful for longer acquisition times (>15 s) in CTA owing to a more favourable uniform enhancement plateau. By contrast, shorter acquisition times (<15 s) for CTA require meticulous scan timing and are shown to benefit from high injection rates or from high iodine concentration in the CM. HCCM is beneficial in achieving an adequate degree of contrast enhancement in CTA. Several earlier studies showed that the use of HCCM produces higher contrast enhancement, even if the total iodine dose and injection rate are unchanged, by increasing the rate of iodine delivery to the vascular system [15–17]. We made similar observations in our study with the use of HCCM. HCCM resulted in superior enhancement (23.5%) in the aorta and its main stem arteries as compared with LCCM ($p\leq 0.05$). Contrary to our observations, Han et al [18, 19] and Ichikawa et al [20] have independently reported a 10% decrease in peak aortic enhancement with HCCM compared with LCCM when a similar fractional iodine

Table 4. Comparison of quantitative enhancement

	Group A	Group B	Group C	p-Value ^a
Magnitude of enhancement in different arteries				
Aorta	208.8 ± 14.2	260.9 ± 30.4	228.1 ± 18.9	0.001
Coeliac artery	210.6 ± 23.2	271.6 ± 32.9	231.4 ± 37.3	0.03
SMA	210.6 ± 21.8	274.2 ± 40.6	235.2 ± 33.1	0.03
Right renal artery	195.6 ± 25.8	256.8 ± 35.6	213.8 ± 26.1	0.019
Left renal artery	191.4 ± 30.2	258 ± 43.6	213.8 ± 26	0.028
Right iliac artery	228 ± 35.9	277.8 ± 21.7	246 ± 26.9	0.052
Left iliac artery	227.4 ± 33.2	277 ± 28.8	255.8 ± 23.1	0.054
Uniformity of aortic enhancement				
Mean interindividual enhancement variation	184.8	536.2	165.8	0.001
Mean maximum-minimum difference	43.8	69.2	33.4	0.001

The Student Newman–Keuls test for pairwise comparison of magnitude of enhancement demonstrated significance only between Groups A and B. Similarly, for uniform enhancement of the aorta, Group B was different from Groups A and C; there was no difference between Groups A and C. SMA, superior mesenteric artery. ^aSignificant difference between groups on one way analysis of variance (ANOVA).

Figure 2. Graphs to demonstrate the variability of aortic enhancement in each group. The x-axis represents multiple levels of measurement in the aorta from the cranial to caudal end, whereas the y-axis represents the absolute degree of enhancement (mean and standard deviation). Aortic enhancement is less variable in Group A (a) and Group C (c), as compared with Group B (b). In Group B, the aorta enhances relatively less at the cranial end compared with the caudal end without a peak enhancement. By contrast, Groups A and C demonstrate approximately similar quantitative enhancement of the aorta at the cranial and caudal ends representing uniform enhancement. ROI, region of interest.

dose was injected. However, these differences are probably owing to the higher injection rates used for LCCM than HCCM in their studies. By contrast, in our study LCCM and HCCM were injected at similar rates, which could account for the higher enhancement obtained with HCCM.

Uniform enhancement throughout the entire vascular territory is highly desirable for CTA to ensure adequate opacification of both proximal and distal aspects of a vascular territory. This feature also improves the quality of post-processing and threshold-dependent quantitative vascular analysis [7]. Different injection protocols have been described in the literature to facilitate uniform aortic enhancement. For example, Fleischmann et al [21] used a biphasic injection protocol where the first bolus was injected at a higher rate than the second bolus; their technique allowed better uniformity in contrast enhancement than uniphasic injection. Similarly, Bae et al [22] used a multiphase injection protocol to achieve uniform aortic enhancement in which the injected volume of CM was exponentially decelerated. Such protocols, although desirable, often add complexity to CT operation and

workflow. Therefore, in our study we used a uniphasic injection protocol (a protocol that simulates routine practice) and compared uniformity of enhancement with different iodine concentrations. We have demonstrated that the use of HCCM results in more variability in aortic enhancement than LCCM. Although reducing the iodine dose by 20% with HCCM reduces variability, it is still found to be higher than for the standard weight-based volume of LCCM; however, this non-uniformity was not appreciated on qualitative assessment. The high variability observed with HCCM (Group B) could result from the reduced volume of CM used and from the acquisition of scans during the first pass of CM (as demonstrated in the aortic enhancement curve with the peak aortic enhancement not yet achieved; Figure 2b). On the other hand, by reducing the volume of HCCM by 20% (Group C) it was possible to acquire scans during the second pass of CM, thus reducing variability.

In our study, we demonstrated that use of HCCM for CTA of the abdomen on 64-slice MDCT could potentially reduce the iodine dose by 20% and still achieve optimal enhancement and image quality. We tested only for a 20%

reduction in HCCM volume, which was selected arbitrarily. Further reduction in volume of HCCM for optimal CTA should be tested. Thus, the use of HCCM for CTA could reduce injection duration and iodine dose, which are highly desirable both for the short duration CTA acquisition times on 64-slice MDCT and for the patient.

Another way to reduce the iodine dose without compromising image quality is through the use of a saline chase following CM injection with a dual-head power injector. Here, the saline bolus flushes the CM into the arterial circulation out of the venous system, thus reducing the required iodine dose. However, the use of a saline flush increases the duration of injection.

There were several limitations to our study. Firstly, this was an experimental study in pigs and the number of study animals in each group was small for comparison. However, the results could be extrapolated to influence clinical practice, because the animals studied were of similar weight to a small-sized adult. Secondly, the study animals were similar in size and weight in the different groups, which was ideal for comparing vascular enhancement with different iodine concentrations. In routine clinical practice, however, human size differs considerably and could influence the results. Thirdly, there was no standard of reference for our observations on the branch order of SMA. In addition, we did not study the effect of reducing the iodine dose or volume using LCCM on CTA quality and enhancement. Although we anticipate less enhancement with a reduced iodine dose or volume of LCCM, the quality of images on CTA needs to be evaluated. Finally, scan delay was determined using a test bolus. Previous studies have suggested that an additional delay (α) should be used on faster scanners, as there is a short delay in peak aortic enhancement on faster scanners such as 64-slice MDCT. Additional α delay was not employed in this study, which could explain the non-uniformity of aortic enhancement observed in Group B.

Conclusion

CTA on 64-slice MDCT provides excellent image quality owing to its high resolution and offers confident visualisation of fourth to fifth order branches of the SMA. The use of HCCM improves the magnitude of contrast enhancement achieved and overall CTA image quality compared with LCCM, despite the total iodine dose being the same. In addition, the use of reduced volumes of HCCM and a reduced total iodine dose confers uniform aortic enhancement to achieve optimal CTA. Thus, HCCM could offer comprehensive benefits in optimising CTA of the abdomen on 64-slice MDCT.

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