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FULL PAPER

Trauma whole-body MDCT: an assessment of image quality in conventional dual-phase and modified biphasic injection

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Objective: To compare the image quality of conventional arterial and portal venous (PV) phase multidetector CT (MDCT) with two biphasic injection protocols in poly-trauma patients.

Methods: 60 consecutive patients with polytrauma underwent body 256-slice MDCT with a conventional protocol or 1 of 2 single-pass biphasic protocols: Group A, arterial (30 s) and PV (60 s) phase acquisitions; Group B, "biphasic" contrast injection with a single acquisition at 60 s; and Group C, "modified biphasic" injection with a single acquisition at a 70-s delay. Images were analyzed for arterial, venous and parenchymal attenuation profiles with regions of interest in the major arteries, veins and solid abdominal organs. A 5-point scoring system was used to assess the image quality, with 5 representing excellent arterial, venous and parenchymal opacification and <3 representing non-diagnostic opacification. In addition, the effective dose (millisieverts) was compared between the groups.

Results: In 93% of patients, image quality was scored as good or excellent (≥ 4). All studies were of satisfactory diagnostic quality. Overall, venous and arterial attenuation profiles were comparable. Attenuation profiles in the solid abdominal viscera were significantly higher ($p < 0.01$) using both biphasic protocols than with arterial or PV phase of conventional protocols. Effective doses were higher in Group A.

Conclusion: Comparable image quality can be achieved using a biphasic i.v. contrast injection protocol with single MDCT acquisition with less radiation and reduction in acquisition time.

Advances in knowledge: For these particular biphasic injection protocols, we have shown that image quality is comparable with a conventional protocol. This has been achieved by comparing enhanced densities of specific structures, as well as gestalt scoring by assessors, on a 256-slice MDCT.

INTRODUCTION

Trauma has been described as a global pandemic, given the high incidence of associated disability and death, despite efforts to control it.¹ In England, there are approximately 20,000 cases of major trauma each year, resulting in 5400 deaths.² Patients with major trauma sustain multiple injuries involving different anatomical areas that are often occult. Therefore, quick and accurate assessment and management, both clinical and radiological, is essential. Several studies strongly support the reliability of multidetector CT (MDCT) in polytrauma.^{3–5} In the UK, whole-body MDCT is the default imaging procedure of choice in the patient who is severely injured in part because the early use of whole-body MDCT significantly improves the probability of survival^{6,7} and can identify patients who require emergency surgery.

Over recent years, biphasic contrast medium injection with a single CT acquisition has been used in both military and civilian settings.^{3,8} Nguyen et al³ first described the biphasic protocol in trauma in 2005 at their trauma centre. After a non-contrast-enhanced CT of the head and cervical spine, a CT of the whole body was obtained with biphasic contrast injection consisting of a 90-ml bolus (iopromide 300 mg l⁻¹) at a rate of 6.0 ml s⁻¹, then a 60-ml bolus at a rate of 4.0 ml s⁻¹. Automatic triggering threshold for scanning was 100 HU at the level of the aortic arch. Median acquisition time and image quality was better for single-pass than for the conventional two-pass protocol. Single pass resulted in a shorter overall scanning time, avoidance of delay due to repositioning and reduction in the time needed for scan programming. However, a monophasic injection of more concentrated contrast medium was preferable to a biphasic injection, as it allowed a slower

injection rate with maintenance of enhancement quality.³ At Camp Bastion, the protocol is a biphasic injection (65 ml at 2 ml s^{-1} , then 95 ml at 3.5 ml s^{-1} with the scan triggering at 70 s whilst the contrast is still flowing in) on a 64-slice MDCT with acquisition from the supraorbital margin to the ischial tuberosity.⁸

Several recent studies make a good case for the use of multi-phasic contrast medium injection, followed by a single-pass scan on MDCT of 64 slice or lower.^{3,9,10} Factors such as image quality, scan duration and radiation dose are important considerations in the patient with polytrauma. Our study assessed two biphasic i.v. injection (or “Combi-scan”) protocols on a 256-slice MDCT, comparing image quality and diagnostic value to the “gold standard” dual-phase conventional arterial and portal venous (PV) phase protocols.

METHODS AND MATERIALS

Retrospective analysis of the diagnostic image quality of whole-body MDCT in 60 patients with major trauma was performed at a Level 1 Trauma Centre in London, UK. Local departmental approval for change in imaging protocol was obtained prior to introduction of the biphasic protocols. The local research and ethics committee approval was obtained.

Patients

Between June 2012 and March 2013, 20 patients were recruited consecutively for each of the 3 groups detailed below ($n = 60$). Only patients arriving between 0900 h and 1700 h on weekdays were selected to reduce the impact of any confounding factors an out-of-hours service may bring. Furthermore, abandoned studies and those with significant metal or arm streak artefact were excluded from analysis.

Equipment and scanning protocols

All examinations were performed on the same 256-slice MDCT system (Philips ICT Brilliance; Philips Healthcare, Best, Netherlands) with a collimation of $64 \times 0.625 \text{ mm}$ and a reconstruction section thickness of 1 mm. A voltage of 120 kV and 180 mAs was used for patients who were normal sized. i.v. contrast medium containing 400-mg l^{-1} iodine (Iomeron-400; Bracco, Milan, Italy) was administered *via* an 18G peripheral cannula using a dual-headed programmable injection pump (Medrad, Warrendale, PA).

Protocols

Group A, conventional protocol: an i.v. injection of 90-ml contrast medium was given at a rate of 3.5 ml s^{-1} . Two spiral acquisitions were made—the first at 30 s to obtain an arterial phase study and the second at 70 s to obtain a PV phase study.

Group B, biphasic protocol: an i.v. injection of 65-ml contrast medium was commenced at a rate of 1.5 ml s^{-1} ; after completion at 43 s, a second 65-ml contrast bolus was started at a rate of 3.5 ml s^{-1} . A single spiral acquisition or “Combi-scan” was made at approximately 60 s.

Group C, modified biphasic protocol: the two contrast boluses were commenced at the same times as in Group B, but there was

a further 9-s delay before acquiring images (total delay 70 s) (Figure 1).

Image evaluation

All imaging was reviewed on a picture archiving and communication system workstation (GE Medical Systems, Milwaukee, WI). Two radiologists (with at least 5 years of trauma radiology experience) independently graded image quality from 1 to 5 (Table 1). Grade 1 was considered to be non-diagnostic, whilst Grade 2 demonstrated poor arterial, venous and parenchymal enhancement such that a confident diagnosis was impossible. Grade 3 was considered diagnostic to exclude life-threatening injuries, but not subtle injuries; for example, good parenchymal enhancement, but suboptimal arterial and venous enhancement. Two additional points were available for optimal vascular opacification and optimal parenchymal enhancement, using a subjective visual assessment. Obtaining one of these would make the study Grade 4 (good), and with both additional points, a study could gain the maximum, Grade 5 (excellent). This score was adapted slightly from previous studies.^{3,9}

The arterial, venous and parenchymal attenuation profiles were generated using 1-cm regions of interest (ROIs) in specific locations (Figure 2). The ROI was carefully positioned in the centre of each blood vessel for vascular opacification (Figure 2a). For the conventional protocol, arterial ROIs were measured in arterial phase imaging and venous ROIs were measured in PV phase imaging. In the solid organs, a 1-cm ROI was placed in parenchyma free of injury, vessels and artefacts where possible (Figure 2b). Renal cortex and medulla were both included in a single ROI. Mean and standard deviation enhancement values (Hounsfield units) were calculated for each scan protocol.

Dose

In order to compare radiation doses, the dose-length product (DLP) (milliGray centimetres) data from each scan was multiplied by conventional conversion factors to calculate the mean effective radiation dose (millisieverts).^{9,11}

Statistical analysis

Unpaired Student's *t*-tests were performed (QuickCalcs; Graphpad Software Inc., CA) to compare the differences between the conventional and two biphasic protocols (contrast enhancement values, image quality and effective dose); $p < 0.05$ was considered to be statistically significant. A Cohen's kappa coefficient (Graphpad Software Inc. CA) was used to assess interobserver variability; $k \geq 0.4$ was considered to show a fair agreement.

RESULTS

Patients

The study population consisted of 46 males and 14 females, aged 43.8 ± 21.5 years (mean $\pm$ standard deviation). The mean ages were 42.9 years in Group A, 47.9 years in Group B and 38 years in Group C. 35 (58%) of the 60 studies demonstrated traumatic injury. This percentage was similar within each group. No injuries were considered “missed” on the review of follow-up studies, subsequent clinical dialogue or discharge summaries. The range of injuries across the three groups was consistent and included pneumothorax, lung contusion, fractures of the ribs,

Figure 1. Diagrammatic representation of scanning protocols. PV, portal venous.

spine and pelvis and lacerations of the liver and spleen. There were only two cases of active bleeding, both within Group C, and one gunshot injury, in Group A.

Image quality

On semi-quantitative review, all studies were considered to be of satisfactory diagnostic quality (≥ 3). For 56 (93%) of 60 patients, image quality was scored as good or excellent (≥ 4); 1 or 2 studies from each group scored 3 (Table 2). The Cohen's kappa coefficient was 0.4, suggesting a fair interobserver agreement.

The conventional protocol, considered the "gold standard", produced the best-quality images; the difference from the biphasic protocols was statistically significant, more so in comparison with Group C ($p < 0.05$). When comparing Group A with Group B or C, a statistically significant higher ratio of studies were of excellent rather than good diagnostic quality. There was no perceived difference in this ratio between Groups B and C. However, when comparing the number of studies, which was good or excellent across each group, there was no significant difference.

Vessels

Arteries

There was a significant reduction in the attenuation of the pulmonary trunk ($p < 0.05$), infrarenal aorta ($p < 0.05$) and

common iliac artery ($p < 0.05$) in the modified biphasic protocol (Group C) in comparison with the conventional protocol (Group A). Otherwise, there was no statistically significant difference in attenuation profiles of the major arteries in the biphasic protocols (Groups B and C) when compared with the conventional protocol (Table 2). The mean density of the portal vein was significantly higher in the biphasic protocols (Group B, $p < 0.0001$; Group C, $p < 0.03$) (Table 3). The mean density of the suprarenal inferior vena cava was also significantly higher in Group C than in Group A ($p < 0.03$).

Solid organ parenchyma

Attenuation profiles of all the solid abdominal viscera were significantly higher ($p < 0.01$) using a biphasic protocol than with the conventional protocol, with the exception of the liver, where enhancement in all three groups was comparable with no statistically significant difference (Table 3).

Dose

There was a clear statistically significant difference between the estimated effective doses (millisieverts) required for the conventional protocol group, in comparison with the single-pass biphasic groups (Table 4). There was also a significant dose difference between the biphasic groups (Groups B and C). There was, however, no difference in the scanning protocol or tube

Table 1. The criteria used to determine the diagnostic quality of a scan

Diagnostic quality (grade)	Criteria
1	Non-diagnostic
2	Poor arterial, venous and parenchymal enhancement. A confident diagnosis would be difficult or impossible
3	Diagnostic to exclude life-threatening injuries, but not subtle injuries
4 (Good) or 5 (Excellent), add one or two criteria	Excellent vascular enhancement
	Excellent parenchymal enhancement

Figure 2. Contrast-enhanced multidetector CT images showing (a) placement of a vascular region of interest (ROI) over the aorta and (b) parenchymal ROIs over the liver and spleen giving mean and standard deviation attenuation values.

voltage. The dose differences between the biphasic groups, therefore, were likely owing to chance: upon reviewing the dose data and scanograms, the differences reflect a higher tube current owing to automodulation based upon the larger average patient body habitus within Group B.

DISCUSSION

Previous studies assessing multiphasic contrast imaging in trauma utilize older CT machines, 16-slice and 64-slice MDCT.^{3,9,10} In this study, 256-slice MDCT was used to assess whether there were differences in the diagnostic quality between biphasic, modified biphasic and conventional i.v. contrast medium injection protocols. This was performed both qualitatively, using a 5-point scoring system, and quantitatively, by measuring the enhanced density of specific thoracoabdominal structures.

Our results show that the image quality scores were comparable across all three protocols for CTs scoring 4/Good or 5/Excellent. However, there was a significant difference in the number of CTs scoring Good or Excellent between the conventional two-pass CTs and the biphasic protocols:

conventional two-pass CTs were more likely to score Excellent than biphasic scans.

Previous investigators have found that biphasic injections with simultaneous arterial and venous enhancement increase the sensitivity of arterial injuries without decreasing the sensitivity of solid organ injury.^{3,5} We have reinforced the findings of the previous studies comparing multiphasic with conventional trauma protocols, also showing that there is better solid organ parenchymal enhancement, thus improving the diagnostic quality.^{3,9,10} As previously suggested, it is likely that both injection boluses and rates utilized in the biphasic protocols produce increased contrast enhancement. In our study, the exception is liver parenchyma, which demonstrated similar enhancement in all three groups, a phenomenon that is likely to be a function of dual supply from both the hepatic artery and portal vein. The results of the vascular enhancement were mixed. Whilst Group C had greater enhancement values within the inferior vena cava and portal vein, than Group A, the enhancement of the pulmonary trunk, infrarenal abdominal aorta and common iliac artery were significantly less. Group B, with the earlier image acquisition, produced a slightly superior arterial enhancement. The venous enhancement, however, was not as good. Overall, the objective image quality in the biphasic protocols was comparable with the individual arterial and PV phase acquisitions in the conventional protocol. In our experience, we found that patients with a lower systolic blood pressure or who were haemodynamically labile had largely arterial phase enhancement on imaging at 60 s. We felt that the 70-s biphasic protocol allowed for this factor.

Biphasic single-pass CT has several advantages over conventional arterial and PV phase CT. Firstly, we have shown that radiation dose to the patient is halved, which is an important consideration, especially given the relative youth of many patients with trauma.^{12,13} Furthermore, our data support that using 256-slice MDCT reduces radiation dose for both dual- and single-pass CTs.^{9,12–14} Radiation dose could also be reduced by performing single-phase PV phase imaging, but this is known to miss important diagnoses such as traumatic splenic pseudoaneurysms.¹⁵ Secondly, as it is already known that error rates are proportionate to the number of studies reported by a radiologist, halving the total number of images to be reviewed may improve the potential error rate in reporting, which is a significant consideration for a busy major trauma centre such as ours.¹⁶ For radiologists who are accustomed to conventional arterial and PV phase imaging, a perception that active bleeding and small pseudoaneurysms are harder to detect with biphasic CT may persist and is borne out by our data—conventional studies were significantly more likely to score Excellent than the biphasic studies. It is for this reason that we still perform conventional two-phase arterial and portal phase MDCT on all penetrating injuries and on patients who are “code red”/patients with major haemorrhage because the risk of solid organ injury and requirement for subsequent radiological or surgical intervention is high.

Our study has several limitations; our i.v. contrast agent contained a higher concentration of iodine compared with previous

Table 2. Image quality assessment results of the two observers, organized by the number of studies obtaining each score within each group

Image quality score	Group A: conventional protocol	Group B: biphasic protocol	Group C: modified biphasic protocol
1	0	0	0
2	0	0	0
3	2	2	3
4	9	25	25
5	29	13	12
Mean	4.68	4.28 ^a	4.23 ^a
Excellent : good ratio	3.22	0.52 ^b	0.48 ^b
Good or excellent	38	38	37

Image quality: 1 = non-diagnostic, 2 = poor, 3 = satisfactory, 4 = good and 5 = excellent.

^aStatistically significant, $p < 0.05$.

^bStatistically significant, $p < 0.0001$.

studies. The contribution of this in creating a comparable vascular and parenchymal enhancement is difficult to quantify. Anecdotally, in one instance, on a Combi-scan, there may have been a more avid enhancement of the liver that reduced the contrast resolution, causing a traumatic pseudoaneurysm to be missed. Following this event, we have changed the contrast agent

from Iomeron-400 to Omnipaque 350 (GE Healthcare, Little Chalfont, UK) and, as mentioned earlier, a conventional protocol is performed when there is a high suspicion of solid organ injury. Scan times were not reviewed in this study but were likely to be quicker in the biphasic than in conventional protocols. Some studies report that multiphasic scans are on an average

Table 3. Mean attenuation measurements of vessels and abdominal solid organs

ROI	Group A: conventional protocol (HU) ^a	Group B: biphasic protocol (HU)	<i>t</i> -test	Group C: modified biphasic protocol (HU)	<i>t</i> -test
Pulmonary trunk	259 ± 17	265 ± 16	0.821	218 ± 17	0.0317 ^b
Ascending aorta	305 ± 16	320 ± 18	0.5491	281 ± 17	0.366
Descending aorta	292 ± 18	305 ± 19	0.5834	277 ± 18	0.55
Infrarenal aorta	305 ± 21	311 ± 24	0.850	256 ± 29	0.05 ^b
Common iliac artery	299 ± 23	303 ± 21	0.862	246 ± 29	0.03 ^b
Common iliac vein	125 ± 24	109 ± 23	0.89	125 ± 24	0.26
Suprarenal IVC	124 ± 28	109 ± 22	0.738	157 ± 35	0.0158 ^b
Infrarenal IVC	118 ± 26	127 ± 30	0.42	124 ± 28	0.279
Portal vein	144 ± 30	191 ± 27	0.0001 ^b	223 ± 29	0.0001 ^b
Right kidney	167 ± 26	210 ± 28	0.0019 ^b	214 ± 41	0.0001 ^b
Left kidney	166 ± 22	210 ± 27	0.0014 ^b	209 ± 42	0.0014 ^b
Spleen	103 ± 24	146 ± 22	0.0001 ^b	165 ± 25	0.0001 ^b
Liver	101 ± 23	97 ± 22	0.567	113 ± 27	0.13

IVC, inferior vena cava; ROI, region of interest.

t-test = *t*-test between values from conventional (Group A) and biphasic (Group B), as well as between conventional (Group A) and modified biphasic (Group C).

^aGroup A artery and vein region of interests were taken in arterial and portal venous phase imaging, respectively.

^b $p < 0.05$ was taken as statistically significant.

Table 4. Mean estimated effective radiation doses

Group	Estimated effective dose (mSv)
Group A: conventional protocol	27.75 ± 6.40 ^a
Group B: biphasic protocol	14.84 ± 2.76 ^a
Group C: modified biphasic protocol	8.86 ± 3.93 ^a

^aStatistically significant, $p < 0.0001$.

approximately 7 s faster than conventional scans.³ However, whether this is clinically relevant is debatable and a recent study on a 64-slice MDCT reported no significant difference in scan times.⁹ Lastly, our cohort of patients was relatively small and so further, larger studies would be of great value.

CONCLUSION

Biphasic injection protocols are robust and easy to use. In polytrauma, a comparable image quality can be achieved

using a biphasic i.v. contrast injection protocol with single MDCT acquisition as with conventional trauma MDCT using separate arterial and PV phase acquisitions. The single acquisition biphasic scan carries less radiation dose, which is of particular importance in a predominantly young cohort of patients. Furthermore, halving of the number of images to review is likely to lower the rate of reporting errors, which is an important consideration in a busy major trauma centre.

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