Title:

Accuracy of Dual Bolus Single Acquisition Computed Tomography in the Diagnosis and Grading of Adult Traumatic Splenic Parenchymal and Vascular Injury.

Running head: Splenic trauma imaging

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Abstract

Introduction:

Dual Bolus Single Acquisition Computed Tomography (DBSA-CT) has been advocated for use in trauma imaging through its ability to concurrently optimise abdominal arterial and visceral parenchymal enhancement while minimising scan times and radiation dose. However, concerns have been raised regarding excessive splenic parenchymal heterogeneity using this technique. The purpose of this study is to establish and compare the accuracy of DBSA-CT to traditional sequential multiphase scanning techniques in the diagnosis and grading of traumatic adult splenic injury.

Methods:

All patients diagnosed with a traumatic splenic parenchymal and/or vascular injury using DBSA-CT at a Level 1 trauma centre, who then proceeded to Digital Subtraction Angiography (DSA) or surgery were used for analysis over the time period June 2014 to March 2016. Two consultant radiologists each independently retrospectively reviewed all CT examinations documenting the degree of splenic heterogeneity, splenic injury grade using the American Association for the Surgery of Trauma (AAST) system and presence of vascular injury. Individual radiologist accuracy and inter-observer variability were evaluated.

Results:

Splenic parenchymal enhancement was diagnostic in all cases with, at worst, moderate splenic heterogeneity. CT AAST parenchymal injury grading correlated poorly with operative findings. Average radiologist diagnostic sensitivity was 50.0% and 38.9% for active arterial haemorrhage and pseudoaneurysm respectively when correlated with DSA findings. Inter-observer agreement ranged from moderate to excellent in all cases.

Conclusion:

DBSA-CT may lead to reduced radiologist accuracy in the diagnosis of splenic injury, particularly pseudoaneurysm, however such conclusions remain tentative given the small patient numbers examined.

Keywords:

Spleen, multidetector computed tomography, trauma, false aneurysm, haemorrhage.

Main Text

Introduction:

Traumatic injury accounts for 9% of global mortality. It is the leading cause of death in those under 45 years of age and is the 6th leading cause of death overall (1-3). Serious head and chest trauma often leads to death at the scene or soon thereafter, whereas patients with severe abdominal trauma frequently survive long enough to receive lifesaving medical care (4).

Full-body Computed Tomography (CT) has revolutionised emergency radiology and trauma management by allowing rapid characterisation of multiple concurrent injuries, facilitating treatment planning and expediting early discharge by excluding occult injuries. However, traditional

sequential multiphase scanning protocols utilising non-contrast, arterial and then portal venous phase CT examinations, expose patients to high radiation doses and a potential increased risk of future malignancy. Dual Bolus Single Acquisition CT (DBSA-CT) combines arterial and portal venous phase abdominal imaging allowing identification of both parenchymal and vascular injuries in a single phase while reducing radiation exposure and scan times (5).

The spleen is the most commonly injured abdominal organ. CT diagnosis of splenic injury, in concert with clinical factors, allows trauma surgeons and interventional radiologists to better personalise patient treatment. Unfortunately, DBSA-CT often leads to heterogeneous splenic enhancement due to varying arterial flow rates through red and white pulp limiting accurate assessment for parenchymal injuries (6, 7).

Methods:

The project was performed at a major Level 1 trauma centre in Melbourne, Australia. Local ethics approval was sought and obtained.

A retrospective analysis was performed. All patients who were admitted to the Alfred Hospital since the introduction of the DBSA-CT scanning protocol (June 2014 – March 2016) with a traumatic splenic injury were included. Of these, only patients, who then proceeded to Digital Subtraction Angiography (DSA) or surgery were analysed.

The hospital Picture Archiving and Communication System (PACS) was used to review all CT examinations and DSA procedures. Patient demographics and operative findings were sourced from the hospital's electronic medical record keeping program PowerChart®. If not specified, the American Association for the Surgery of Trauma (AAST) splenic injury grade was extrapolated from the operative description provided.

The CT scanner utilised was a Toshiba Aquilion ONE™ 320-row detector scanner with a dual injection biphasic abdominopelvic trauma scanning protocol. Firstly, 80 ml of Omnipaque™350 (GE Healthcare, subsidiary of General Electric Company) is delivered intravenously at 4 ml/second. After

a 20 second delay a further 60 ml of Omnipaque™350 is delivered followed by a 50ml normal saline chaser, both also delivered at 4ml/second. Image acquisition is manually triggered once a threshold of 180 Hounsfield Units (HU) is reached within the lumen of the descending thoracic aorta. The outcome is that of a mixed arterial and portal venous phase examination of the abdomen and pelvis from diaphragm to pubic symphysis (Figure 1).

The effective abdominopelvic radiation dose received by patients in millisieverts (mSv) was calculated by multiplying the Dose Length Product (DLP), measured in mGy.cm, by the abdomen-pelvis conversion factor as a function of peak kilovoltage (kVp) and age as per the International Commission on Radiological Protection (ICRP) guidelines publication 103 (8).

Each CT scan was individually and independently reviewed by 2 qualified radiologists, one with 9 years experience (JB) and the other with 3 years experience (PK). Thus, each patient received two “readings” of each variable under investigation. Radiologists were blinded to all operative and angiographic outcomes, as well as each other’s findings.

Radiologists were first asked to assess the degree of splenic heterogeneity using a Visual Analogue Scale (VAS) adapted from Loupatatzis et al (9). Splenic heterogeneity was graded from 1 – 5 (1 =non-diagnostic; 2 = severe; 3 = moderate; 4 = mild; 5 = none). Radiologists also documented the AAST injury grade and the presence or absence of active splenic bleeding and/or pseudoaneurysm. Abdominal aortic and portal vein densities were obtained at the level of the coeliac axis and mid portal vein respectively using the Region of Interest (ROI) tool by the study investigator.

Inter-observer variability was assessed using the kappa statistic (0.01-0.20 = slight or poor, 0.21-0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = substantial or good and 0.81-0.99 = almost perfect or excellent). Weighted kappa scores penalise greater divergence, and this was used in calculations pertaining to splenic heterogeneity and splenic parenchymal AAST grading. (10).

Results:

A total of 36 patients met the study inclusion criteria, which include 26 males and 10 females with an average age of 39 (range 17-84). The DSA and surgical treatment groups comprised 28 and 8 patients respectively. One patient, who proceeded to DSA, was excluded due to a non-diagnostic angiogram. Four patients, who proceeded to surgery, were excluded due to their operative notes lacking sufficient detail regarding the type and severity of splenic injury, preventing an AAST grade to be accurately assigned. Patients sustained a range of injuries including motor vehicle, motorbike and pushbike accidents, as well as horse riding injuries and assault.

Patients received an average abdominopelvic DLP radiation dose of 895.2 mGy.cm (range 449.7 – 2098.0 mGy.cm) corresponding to a mean effective radiation dose of 12.6 mSv (range 6.3 mSv – 29.6 mSv).

Splenic image quality was diagnostic in all cases. VAS scores ranged from 3 – 5 with a mean of 4.3 (Figure 2). The average abdominal aortic and portal vein densities were 325 HU (range 139 HU – 466 HU) and 193 HU (range 133 HU – 283 HU) respectively. Radiologist accuracy with respect to vascular injury diagnosed with DSA are presented in Tables 1 and 2. Radiologists demonstrated excellent (kappa 0.81) and moderate (kappa 0.53) agreement when reporting the presence of active splenic haemorrhage and pseudoaneurysm respectively.

The grading of splenic parenchymal injury with surgical correlation is displayed in Table 3. Inter-radiologist agreement was moderate with a weighted kappa score of 0.58. Radiologist 1 and Radiologist 2 demonstrated poor (kappa 0.19) and moderate (kappa 0.52) agreement with operative findings.

Discussion:

Trauma imaging practices vary between institutions, namely, with respect to the use of sequential multiphase or DBSA scanning techniques. Splenic visceral injury is best assessed with portal venous phase imaging where organ density homogeneity is optimised (11). However, coexistent visceral and vascular injury is seen in 5 – 25% of polytrauma patients. Active arterial extravasation is best visualised in the portal venous phase, however contained vascular injury is often invisible and requires arterial phase imaging for detection (12-15).

The use of DBSA-CT has been advocated in recent years to image the abdomen in both arterial and portal venous phases simultaneously to maximise diagnostic sensitivity while minimising scan times and radiation doses, the latter reduced by up to 49% when compared to multiphase techniques (5, 16). However, red pulp demonstrates more rapid arterial contrast enhancement due to bypass of the reticuloendothelial system leading to heterogeneous splenic enhancement on DBSA-CT (17).

Patients were exposed to a mean radiation dose of 12.6 mSv, which compares favourably to multiphase abdominopelvic CT scanning protocols in North America, Europe and Australia (18-20), which often reach doses as high as 31 mSv. Three patients were exposed to radiation doses upwards of 20 mSv (21.3 mSv, 27.9 mSv and 29.6 mSv). Due to their large body habitus they were scanned using a rotation time of 0.5 seconds, instead of 0.35 seconds, and one patient was scanned at 135 kV rather than the standard 120 kV.

Surprisingly, patients were exposed to a mean radiation dose 2.3 times greater than those in the study performed by Leung et al. Using a Somatom Definition AS+ (Siemens Healthcare) CT scanner, Leung et al employed a DBSA-CT scanning protocol and calculated radiation doses over a larger scan range - Circle of Willis to the pubic symphysis (16). Whilst not only providing a lower radiation dose when compared to our institution's DBSA-CT protocol, the larger scan range allows simultaneous evaluation of cervical spine fractures and vascular injury, occurring concurrently in up to 46% of cases (21). At our institution CT carotid angiography is only performed in the setting of trauma when neck bruising, penetrating neck wounds, posterior cerebral circulation neurological symptoms or foramen transversarium fractures are observed.

The traditional multiphase trauma scanning protocol used by Leung et al, utilising an arterial phase examination from the lung apices to the pubic symphysis followed by a portal venous phase examination from the diaphragm to the pubic symphysis, carried a mean radiation dose 1.9 mSv less than the DBSA-CT protocol at our institution. These observations are peculiar and further analysis of the scan parameters used by Leung et al, many of which were not documented, are required to elucidate the reasons behind this.

Splenic image quality was diagnostic in all cases. Splenic heterogeneity was observed in 43/72 readings (34/72 mild and 9/72 moderate heterogeneity). These results mirror the findings of Stedman et al, who found 71/73 studies were diagnostic and 36/73 patients demonstrated some degree of splenic heterogeneity (22). In tandem, these studies show that even when splenic heterogeneity is observed, diagnostic image quality is maintained.

Average suprarenal abdominal aortic and portal vein densities were superior to those observed in the single phase arterial and portal venous phase examinations listed by Loupatatzis et al with densities measuring 324 HU v. 308 HU and 193 HU v. 125 HU respectively (9). Vascular enhancement can still be improved. Erturk et al achieved peak aortic and portal vein densities of 398 HU and 238 HU following time delays of 35 seconds and 46 seconds from contrast bolus initiation respectively (23-25). Arterial and portal venous enhancement is achieved at approximately 15 seconds and 55 seconds following contrast bolus initiation at our institution using the DBSA-CT protocol. Timing modification may aid in improving vascular enhancement.

Contrary to the studies performed by Shapiro and Sutyak, splenic parenchymal injury was more likely to be over-graded pre-operatively with average CT and surgical splenic AAST injury scores of 3.0 v. 2.4 respectively (26, 27). Only 6% of readings correlated exactly with surgical findings, compared to 29% in the study performed by Sutyak et al (27).

Amongst the 10/16 readings, which were over-graded pre-operatively, two patients were found to have a normal spleen at laparotomy, yet received an AAST score of up to III. On repeat review, one patient demonstrated a developmental cleft, which was mistaken for a laceration in the presence of intra-abdominal fluid, and the second patient did not have a visible injury. Both patients demonstrated homogenous splenic enhancement. Patient 2, who received a unanimous CT AAST score of V, was given an intra-operative grade of III. On review of the imaging the injury was without question an AAST grade V injury (Figure 3).

Of the 5/16 readings, which were under-graded pre-operatively, 4/5 were discordant by only 1 AAST grade and the other by 2 AAST grades. The under- or over-grading of splenic injury can be attributed to both radiological and surgical factors.

208

209 Radiological AAST injury grading requires further refinement through specifying and standardising
210 the anatomical plane in which to measure organ lacerations or haematomas. Alternatively, a
211 modified CT diagnostic system may be required, which provides clear clinical direction without the
212 need for standardised injury scoring. Research suggests that the presence of a CT contrast blush
213 (Baltimore Injury Scale), volume of haemoperitoneum (University of Massachusetts CT Grading
214 Sytem) and haemodynamic instability are the main factors driving intervention (28, 29). The
215 presence and degree of parenchymal injury in isolation is of dubious clinical significance.

216

217 Surgery, long considered the gold standard in many facets of medicine, also has limitations. The
218 visualisation and grading of splenic injury is subjective, capsular injury can be masked by perisplenic
219 fluid and laparotomy is associated with a small rate of missed injury (30). The inconsistent operative
220 grading of splenic injury, as seen in this study, implies inherent difficulties in the process and may
221 have also lead to interpretation errors on behalf of the investigator.

222

223 Diagnostic accuracy of DBSA-CT in the diagnosis of active haemorrhage and pseudoaneurysm fell
224 well short of previously published data, which is likely a function of the small patient cohort (Tables
225 4 and 5) (31). However, both radiologists expressed frustration and apprehension in differentiating
226 active contrast extravasation from pseudoaneurysm when a contrast blush was visualised without
227 the aid of delayed phase imaging (Figure 4). Greatest inter-radiologist variability was observed when
228 diagnosing pseudoaneurysm (kappa score of 0.53) further supporting their unease. Distinguishing
229 the cause of a CT contrast blush may be academic, as patients require DSA evaluation in any respect
230 (32, 33).

231

232 Interestingly, 4/9 patients with a pseudoaneurysm had no CT contrast blush. These patients
233 demonstrated lower average aortic densities (299 HU v. 394 HU) implying incorrectly (late) timed
234 arterial phase examinations leading to a lack of pseudoaneurysm enhancement. Alternatively, 2 of
235 these patients had a time delay of 24 hours 58 minutes and 19 hours 1 minute between initial CT
236 and DSA, allowing time for delayed pseudoaneurysm formation.

237

238 Conclusion:

239

240 DBSA-CT does not lead to excessive splenic heterogeneity, however concerns are raised over its
241 utilisation for traumatic splenic vascular injury with diagnostic sensitivity and specificity well below
242 sequential multiphase techniques, although results are almost certainly confounded by small patient
243 numbers. The poor correlation between radiological and surgical AAST splenic injury grading
244 continues to breed scepticism over its clinical value. DBSA-CT may over-estimate the degree of
245 parenchymal splenic disruption, potentially leading to unnecessary and excessive intervention.

246

247 Acknowledgements:

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Appendices:

Figure Legends:

Figure 1: Axial plane CT at the level of the spleen utilising a DBSA-CT scanning protocol.

CT: Computed Tomography; DBSA: Dual Bolus Single Acquisition; 1: Portal vein; 2: Abdominal aorta; 3: Spleen

Figure 2: Examples of splenic heterogeneity observed in study participants.

a: No splenic heterogeneity; b: Mild splenic heterogeneity; c: Moderate splenic heterogeneity

Figure 3: CT AAST grade 5 splenic injury diagnosed as an intra-operative AAST grade 3 injury.

Figure 4: Misinterpretation of splenic contrast blush.

a: Large splenic contrast blush (arrow) interposed within a laceration (arrow head) was interpreted as a pseudoaneurysm by both radiologists. Splenic contusion (open arrow) and upper abdominal haemoperitoneum (star) are also present. b: Splenic artery catheter angiogram demonstrates active arterial extravasation (arrow) from the lower pole of the spleen corresponding to the large contrast blush identified on computed tomography. c: Haemostasis achieved with gelfoam and coils.

Table Legends:

Table 1: Radiologist accuracy in the diagnosis of active splenic haemorrhage.

R1: Radiologist 1; R2: Radiologist 2

Table 2: Radiologist accuracy in the diagnosis of splenic pseudoaneurysm.

R1: Radiologist 1; R2: Radiologist 2

Table 2: Radiologist AAST splenic injury grading with surgical correlation.

R1: Radiologist 1; R2: Radiologist 2; AAST: American Association for the Surgery of Trauma

Table 3: Sensitivity and specificity of scan protocols in the diagnosis of active splenic haemorrhage.

Reference 31 is the source of data for columns 2-4 and values from the current study are supplied in column 5. DBSA: Dual Bolus Single Acquisition

Table 4: Sensitivity and specificity of scan protocols in the diagnosis of splenic pseudoaneurysm.

Reference 31 is the source of data for columns 2-4 and values from the current study are supplied in column 5. DBSA: Dual Bolus Single Acquisition; N/A: Not

Applicable. Pseudoaneurysms are typically invisible on portal venous phase imaging

	R1	R2
Sensitivity	42.9% (95% CI: 9.9% - 81.6%)	57.1% (95% CI: 18.4% - 90.1%)
Specificity	81.0% (95% CI: 58.1% - 94.6%)	85.7% (95% CI: 63.7% - 97.0%)

Table 1

	R1	R2
Sensitivity	44.4% (95% CI: 13.7% - 78.8%)	33.3% (95% CI: 7.5% - 70.1%)
Specificity	57.9% (95% CI: 33.5% - 79.7%)	84.2% (95% CI: 60.4% - 96.6%)

Table 2

Patient	CT AAST		Surgical AAST
	R1	R2	
1	II	II	I
2	V	V	III
3	III	III	IV
4	II	II	I
5	IV	V	V
6	II	I	0
7	III	I	0
8	III	IV	V

Table 3

	Scan protocol			
	Arterial	Portal venous	Multiphase	DBSA
Sensitivity	70%	93%	97%	50%
Specificity	98%	100%	100%	83%

Table 4

	Scan protocol			
	Arterial	Portal venous	Multiphase	DBSA
Sensitivity	70%	N/A	90%	39%
Specificity	95%	N/A	100%	71%

Table 5

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