Emerg Radiol (2014) 21:491–498
DOI 10.1007/s10140-014-1227-z

ORIGINAL ARTICLE

Characterization of indeterminate spleen lesions in primary CT after blunt abdominal trauma: potential role of MR imaging

Sonja Gordic · Hatem Alkadhi · Hans-Peter Simmen · Guido Wanner · Dieter Cadosch

Received: 7 March 2014 / Accepted: 14 April 2014 / Published online: 1 May 2014

Abstract The purpose of this study was to determine the value of magnetic resonance imaging (MRI) for characterization of indeterminate spleen lesions in primary computed tomography (CT) of patients with blunt abdominal trauma. Twenty-five consecutive patients (8 female, 17 male, mean age 51.6±22.4 years) with an indeterminate spleen lesion diagnosed at CT after blunt abdominal trauma underwent MRI with T2- and T1-weighted images pre- and post-contrast material administration. MRI studies were reviewed by two radiologists. Age, gender, injury mechanism, injury severity score (ISS), management of patients, time interval between CT and MRI, and length of hospital stay were included into the analysis. Patient history, clinical history, imaging, and 2-month clinical outcome including review of medical records and telephone interviews served as reference standard. From the 25 indeterminate spleen lesions in CT, 11 (44 %) were traumatic; nine (36 %) were non-traumatic (pseudocysts, n=5; hemangioma, n=4) and five proven to represent artifacts in CT. The ISS (P<0.001) and the length of hospital stay (P=0.03) were significantly higher in patients with spleen lesions as compared with those without. All other parameters were similar among groups (all, P>0.05). The MRI features ill-defined lesion borders, variable signal intensity on T1- and T2-weighted images depending on the age of the hematoma, focal contrast enhancement indicating traumatic pseudoaneurysm, perilesional contrast enhancement, and edema were most indicative for traumatic spleen lesions. As compared with CT (2/25), MRI (5/25) better depicted thin subcapsular hematomas as indicator of traumatic spleen injury. In conclusion, MRI shows value for characterizing indeterminate spleen lesions in primary CT after blunt abdominal trauma.

Keywords Blunt abdominal trauma · Spleen · Indeterminate lesion · Magnetic resonance imaging · Computed tomography

S. Gordic · H. Alkadhi (✉)
Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, Rämistrasse 100, 8091 Zurich, Switzerland
e-mail: hatem.alkadhi@usz.ch

H.-P. Simmen · G. Wanner · D. Cadosch
Clinic of Trauma Surgery, University Hospital Zurich, Zurich, Switzerland

Introduction

The spleen is one of most frequently injured organs after blunt abdominal trauma, accounting for up to 49 % of all visceral injuries [1, 2]. Since physical examination and laboratory data are often nonspecific in the diagnosis of splenic injury [3], imaging with ultrasound or computed tomography (CT) usually is required for diagnosing or ruling-out traumatic spleen injury [4]. Contrast-enhanced CT is currently considered the imaging tool of choice for the assessment of traumatic visceral injury in hemodynamically stable patients due to its widespread availability, speed, minimally invasive nature, and accuracy [5]. Besides the ability of CT for diagnosing traumatic splenic injury, it is also able to demonstrate coexisting pathology, such as injury to the liver, retroperitoneum, and abdominal wall and can exclude lesions requiring surgery, such as bowel or pancreatic injuries [6]. The use of CT has also influenced current trends in the management of traumatic spleen injuries towards nonsurgical approaches including catheter-based interventions [7, 8].

Notwithstanding the clinical value of CT imaging in trauma patients [9], the interpretation of especially smaller hypodense lesions of the spleen can be challenging [10], not only because of sometimes coexisting artifacts [11]. This is explained by the fact that hypodense lesions in the spleen have a high prevalence in the general population, often being an incidental and benign finding. In addition, soft tissue contrast is limited in CT, which limits the capability of the modality to further

differentiate incidental from traumatic spleen lesions. The existence of a hypodense spleen lesion thus might complicate the evaluation of patients with blunt abdominal trauma, potentially leading to unnecessary interventions, prolonged hospital stay, and increased treatment costs.

Magnetic resonance (MR) imaging offers better soft tissue contrast than CT, is often used for the evaluation of the upper abdomen [12], and thus has the potential for helping in the differentiation of traumatic and non-traumatic spleen lesions.

The purpose of this study was to determine the value of MR imaging for characterization of indeterminate spleen lesions in the primary CT of patients with blunt abdominal trauma.

Material and methods

Patients

This retrospective study was conducted at a level-I trauma center after institutional review board and local ethics committee approval was obtained. Written informed consent was waived because of the retrospective nature of the study.

Between July 2010 and May 2013, a total of 996 patients were admitted to our hospital after blunt abdominal trauma. From these, 173 (17 %) showed a splenic lesion in primary CT of which 25 (15 %) were judged by the attending fellow and senior staff radiologist on duty as indeterminate. The indeterminate nature of these spleen lesions were confirmed by two other experienced radiologists involved in this study who read all primary CT studies again.

Among these 25 patients (8 female, 17 male, mean age 51.6±22.4 years; age range, 22–86 years), fall (68 %) accounted for the major mechanism of injury followed by sports injury (20 %) and motor vehicle accident (12 %) (Table 1).

Further characterization of these indeterminate spleen lesions was performed with MR imaging within a median time interval of 24 h after CT (range, 4 h to 9 days).

CT imaging

According to our institutional trauma protocol, all 25 patients underwent whole-body CT including imaging of the head, cervical spine, chest, and abdomen, the latter two body regions after the administration of contrast media. All CT studies were performed using a first generation dual-source CT machine (Somatom Definition; Siemens Healthcare, Forchheim, Germany). All patients were placed on the CT table in supine position. The following scan and reconstruction parameters were kept identical for all data acquisitions in all examinations: tube voltage 120 kV; reference tube current–time product 250 mAs using attenuation-based tube current modulation (CareDose 4D; Siemens); pitch 1.5; slice collimation 32×0.6 mm, slice acquisition 64×0.6 mm by means of a z-flying focal spot, gantry rotation time 330 ms; slice thickness 2 mm; increment 1.6 mm, using filtered back-projection.

In all patients, a 100-ml bolus of iso-osmolar, non-ionic iodinated contrast material [300 mg iodine/ml, Iopromide (Ultravist 300; Bayer Schering Pharma)] followed by a saline flush of 40 ml was injected into an antecubital vein at a flow rate of 3 ml/s. Contrast media injection was timed for obtaining a mixed arterio-venous enhancement of the chest and a portal-venous enhancement of the abdomen.

MR imaging

All MR imaging was performed on a 1.5 Tesla whole body MR scanner (SignaEchospeed EXCITE HDxt, GE Healthcare, Waukesha, WI, USA) with patients in supine position using an eight-element body-array coil. All patients received a 22-gauche intravenous catheter in an antecubital vein for contrast media administration.

Overview and calibration sequences for surface-coil sensitivity were acquired in inspiration. The imaging protocol comprised 2D encoded coronal T2-weighted single-shot fast spin-echo sequences (TR/TE 1275/92.4 ms, flip-angle 90°,

Table 1 Patient demographics and injury characteristics

	Patients, overall	Patients with traumatic spleen lesion (n=11)	Patients w/o traumatic spleen lesion (n=14)	P value
Age (mean ± SD) in years	51.6±22.4	52.0±19.2	51.3±25.3	0.939
Sex (% male)	68 % (17/25)	63.6 % (7/11)	71.4 % (10/14)	0.678
Sports injury	5 (20 %)	2	3	0.700
Motor vehicle accident	3 (12 %)	2	1	
Fall	17(68 %)	7	10	
ISS (mean ± SD)	15.98±12.5	25.1±10.2	8.6±8.8	<0.001
Time between CT and MRI (mean ± SD, in hours)	46.6±55.9	69.2±76.2	28.9±23.1	0.072
Interventional versus conservative management	2 (8 %)	2 vs. 9	0 vs. 14	0.096
Length of hospital stay (mean ± SD, in days)	8.6±6.8	11.8±5.7	6.1±6.6	0.030

ISS injury severity score, *SD* standard deviation, *CT* computed tomography, *MRI* magnetic resonance imaging

matrix size 384×224, FOV 480 mm, slice thickness 6 mm, intersection gap 1 mm, bandwidth 244.1 Hz/Px), axial 2D encoded T2-weighted fat-suppressing fast spin-echo sequences (TR/TE 10588.2/104.5 ms, flip angle 90°, matrix size 256×256 mm, FOV 400 mm, section thickness 5 mm, bandwidth 162.8 Hz/Px) and contrast-enhanced (Gd-DOTA, Dotarem, Guerbet, France, 0.2 mmol/kg body weight; flow rate 1.5 ml/s) dynamic acquisitions with a T1-weighted 3D spoiled SPGR sequence (LAVA FLEX, GE Healthcare) (TR/TE 3.1/1.4 ms, flip angle 15°, matrix size 256×224 mm, FOV 400 mm, slice thickness 4 mm, none intersection gap, bandwidth 325.5 Hz/Px). Total examination time was 17 min.

Image analysis was performed on LCD monitors (EIZO FlexScan S2100) of the picture archive and communication system (PACS) (Impax 6.0 by Agfa HealthCare) of our hospital.

Imaging evaluation

MR images were reviewed in consensus by two radiologists having 3 and 6 years of experience in MR imaging. The following features were determined: border definition, signal intensity on T1-weighted pre- and post-contrast images, signal intensity on T2-weighted images, contrast enhancement of the lesion, number of spleen lesions per patient, perilesional contrast enhancement, and edema, subcapsular, and perisplenic fluids.

Reference standard

Meticulous case ascertainment, clinical examination, and interpretation of all available imaging examinations (including CT, ultrasound, and catheter angiography, if available) served as the reference standard. In addition, clinical follow-up 2 months after hospital discharge in the out-patient clinic or telephone interview was performed in all patients.

Statistical analysis

Quantitative variables were expressed as mean ± SD and categorical variables as frequencies or percentages.

Unpaired Student's *t* test for independent samples was used to test for significant differences between patients with traumatic and non-traumatic spleen lesions regarding age, injury severity score (ISS), time interval between CT and MR imaging, and length of hospital stay.

The Chi-square test was used to test for significant differences between patients with traumatic and non-traumatic spleen lesions regarding gender, injury mechanism, and management of patients.

P values <0.05 were considered statistically significant. All statistical analyses were performed using commercially available software (SPSS, release 21, Chicago, IL).

Results

Patients

There were no significant differences between the 11 patients with and those 14 without traumatic spleen lesions regarding age, gender, injury mechanism, time interval between CT and MR imaging, and management of patients (all $P>0.05$, Table 1). Patients with traumatic spleen injury had a significantly higher ISS ($P<0.001$) and a longer hospital stay ($P=0.03$) as compared with those without. Two of the 11 (18.2 %) patients with traumatic spleen injury underwent embolization of the splenic artery (Table 1).

CT imaging findings

All 25 patients showed a hypodense lesion in the spleen on portal-venous phase CT. Measurements of Hounsfield unit (HU) values were inconclusive in small lesions because of partial volume artifacts. Three of the 25 patients (12 %) showed perisplenic fluid on primary CT. There were no adjacent traumatic findings that would have suggested a traumatic origin of the hypodense spleen lesions in any of these patients. Additional imaging findings in the abdomen related to trauma included liver laceration ($n=3$), hematoma of the right adrenal gland ($n=1$), hematoma of the psoas muscle ($n=1$), and basal rib fractures ($n=2$).

MR imaging findings

Non-traumatic spleen injury Nine of the 25 (36 %) spleen lesions in CT were of non-traumatic etiology. All showed a well-defined, sharply demarcated hyperintense signal on T2-weighted and a hypointense signal on non-enhanced T1-weighted images. After administration of contrast media, 5/9 lesions (55 %) showed no enhancement, consistent with (pseudo-)cysts (Table 2), whereas 4/9 showed a nodular peripheral enhancement on venous phase images, consistent with hemangioma (Fig. 1). Contrast media uptake could not be appreciated in these four lesions on CT.

MR imaging was normal in five of the 25 (20 %) patients showing hypodense lesions in CT. In two of these patients, the abnormality on CT most probably was due to beam hardening artifacts. In one patient, the lesion represented a perfusion inhomogeneity due to contrast media administration problems. In one patient, the hypodense lesion in CT turned to be a bi-lobulated spleen according to MR imaging. In the last one, CT was interpreted as showing subcapsular fluid, whereas MR imaging showed no splenic and perisplenic abnormality but rather an asymmetric thickening of the diaphragm leading to a false-positive diagnosis on CT (Fig. 2).

Table 2 MR imaging findings in patients after blunt abdominal trauma with indeterminate spleen lesions in primary trauma CT

	n	T2-weighted	T1-weighted non-enhanced	T1-weighted contrast-enhanced	Lesion demarcation	Perilesional signal alterations	Free perisplenic fluid	Subcapsular hematoma	Interpretation
Traumatic spleen lesions (n=11)	3	Hyperintense	Iso-/hypointense	Hypointense	Ill-defined		3/11 (27.3 %)	5/11 (45.5 %)	Hyperacute hemorrhage
	3	Hypointense	Slightly hypointense	Hypointense	Ill-defined				Acute hemorrhage
	3	Hypointense	Hyperintense	Hypointense, one patient showed a focal, nodular enhancement (pseudoaneurysm)	Ill-defined				Early subacute hemorrhage
	2	Hypointense	Hyperintense	Hypointense	Ill-defined	T2 hyperintensity (edema), slight contrast enhancement (granulation tissue)			Late subacute hemorrhage
Non-traumatic spleen lesions (n=9)	4	Hyperintense	Hypointense	Hypointense - peripheral nodular enhancement	Sharp demarcation	None	1 (11 %)	0 (0 %)	Hemangioma
	5	Hyperintense	Hypointense	Hypointense—no enhancement	Sharp demarcation	None			Cyst

Traumatic spleen injury Eleven of the patients (44 %) had traumatic spleen injury. All demonstrated a heterogeneous signal behavior at MR imaging, depending on the interval between trauma and MR imaging (Table 2). Three patients showed an ill-defined hyperintense signal on T2-weighted images, most probably representing hyperacute hemorrhage. Catheter angiography in one of these three patients showed an active central splenic hemorrhage. All other eight patients demonstrated ill-defined hypointense lesions on T2-weighted images, most probably representing acute and subacute hemorrhage. Two patients showed a slight hyperintense rim around the lesion at T2-weighted images, most probably representing perifocal edema (see Table 2).

T1-weighted images showed an isointense signal of the lesion in two patients with hyperacute hemorrhage and a hypointense signal in three patients with acute hemorrhage. Five patients with subacute hemorrhage showed a hyperintense signal on T1-weighted images. On contrast-enhanced images, one patient showed a focal, nodular hyperintense lesion in arterial phase images suggesting a pseudoaneurysm, which was confirmed at catheter angiography. The lesions in the other ten patients showed no contrast enhancement. Two patients with subacute hemorrhage showed a perifocal contrast enhancement, most probably representing granulation tissue.

Five out of 11 (46 %) patients demonstrated a subcapsular hematoma, of which three were not detected on CT (Fig. 3). Three of 11 (27.3 %) showed free perisplenic fluid, of which one was not seen on CT.

Follow-up

In all nine patients in whom the indeterminate spleen lesion on CT was interpreted as being a benign, incidental finding according to MR imaging, no further imaging studies (including CT, ultrasound, catheter angiography, and MR imaging) of the spleen were performed during their hospital stay. Clinical follow-up after 2 months in these patients revealed no evidence of traumatic spleen injury. In contrast, in the 11 patients with presumably traumatic spleen lesions, further imaging was performed including ultrasound (n=10), CT (n=4), and catheter angiography including embolization (n=1).

Discussion

The accuracy of contrast-enhanced CT for the evaluation of traumatic visceral injury is well established with reported sensitivities and specificities ranging from 93 to 96 % [13, 14]. Portal-venous phase CT imaging is considered the standard for evaluating patients after abdominal trauma [15]. However, interpretation of focal hypodense lesions of the spleen can be challenging with CT [10]. Artifacts or benign

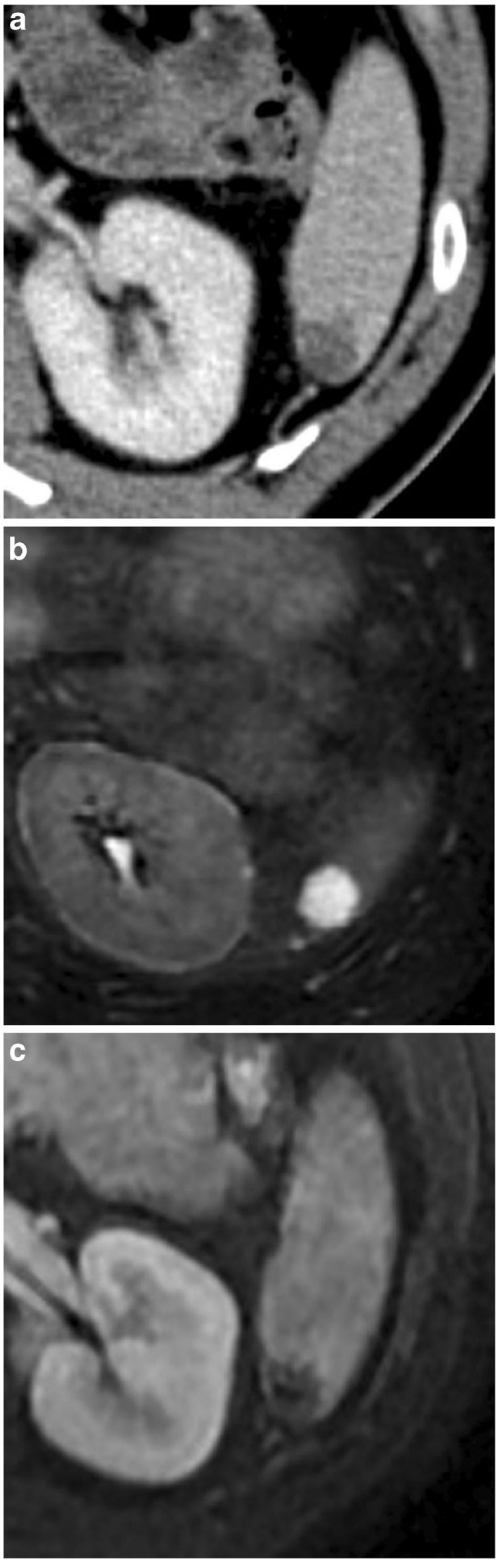


Fig. 1 A 45-year-old male patient with blunt abdominal trauma after fall. **a** Transverse portal-venous phase CT shows a hypodense lesion of the posterior pole of the spleen. **b** T2-weighted MR images at the same level demonstrate a well demarcated, homogenously hyperintense lesion. **c** Contrast-enhanced T1-weighted MR images in the venous phase shows a nodular, peripheral enhancement indicating hemangioma

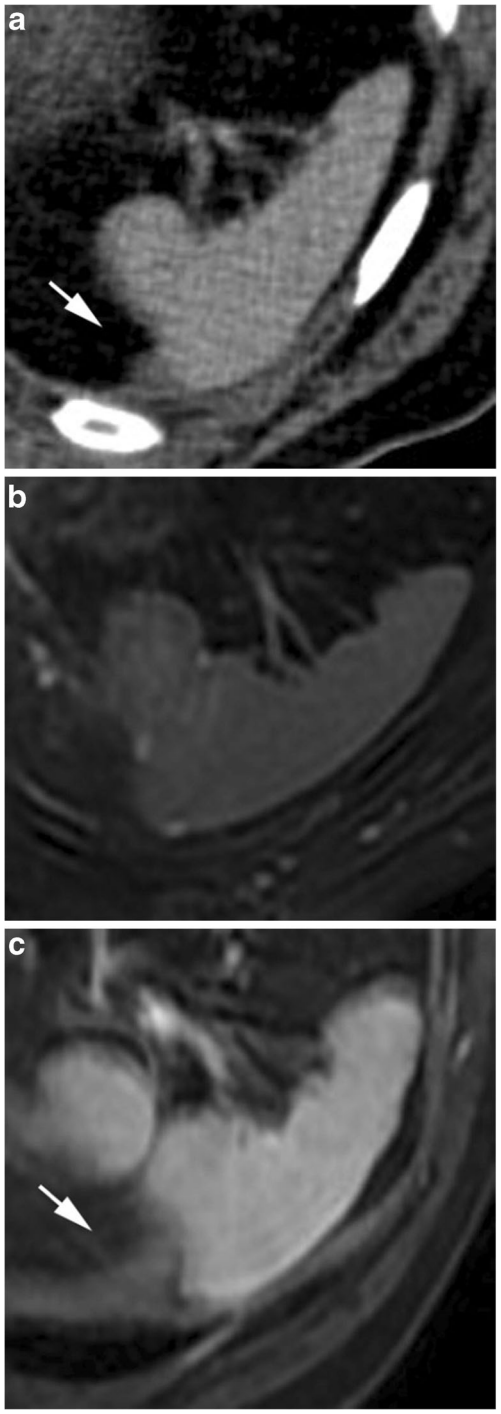
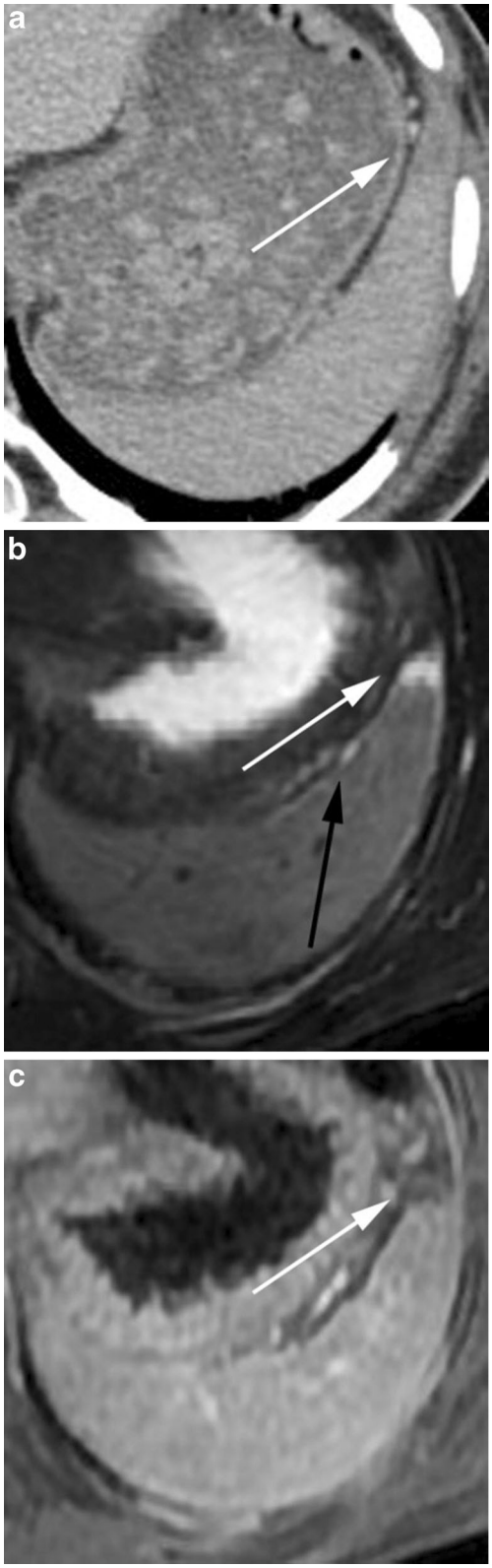


Fig. 2 A 71-year-old male patient with blunt abdominal trauma after fall. **a** Transverse portal-venous phase CT were interpreted as showing perisplenic fluid (*arrow*). **b** T2-weighted MR images at the same level demonstrate a normal configured spleen without a lesion or perisplenic fluid. **c** Contrast-enhanced T1-weighted MR images in the venous phase shows thickening of the diaphragm (*arrow*) mimicking perisplenic fluid at CT

lesions of the spleen such as hemangioma or pseudocysts may render the interpretation of spleen lesions in trauma patients difficult.

Driven by the hypothesis that MR imaging provides an improved contrast and soft tissue resolution as compared with



◀ **Fig. 3** A 25-year-old woman with blunt abdominal trauma after motor vehicle accident. **a**Transverse portal-venous phase CT shows a mild hypodensity at the ventral pole of the spleen (*white arrow*). **b** T2-weighted MR images at the same level demonstrate an ill-defined hyperintense lesion (w*hite arrow*) with a thin subcapsular hematoma (*black arrow*). **c** Contrast-enhanced T1-weighted MR images in the venous phase show a small hypointense lesion (*white arrow*), indicating hyperacute intra-parenchymal hemorrhage

CT, we sought to determine the value of MR imaging as follow-up imaging modality for further characterization of indeterminate spleen lesions at primary CT. According to the experience in this study, we believe that the following MR imaging features are helpful in the diagnosis of benign, incidental lesions: sharp lesion border demarcation and high signal on T2-weighted images, no or nodular peripheral enhancement of the lesion. In contrast, traumatic spleen lesions showed ill-defined borders with variable signal intensities on T1- and T2-weighted images. Contrast enhancement within the lesion was seen in only one patient with a pseudoaneurysm, and perilesional contrast enhancement and edema were seen in patients with MR imaging at 9 and 10 days after trauma.

Interpretation of acute traumatic injury in MR imaging requires knowledge about the imaging features of the different stages of blood in the various sequences, which is known primarily for intracerebral hemorrhage [16]: A hyperacute hematoma (oxyhemoglobin) has an isointense to slightly hyperintense signal intensity on T1-weighted and increased signal intensity on T2-weighted images. In the acute phase (intracellular deoxyhemoglobin), the signal intensity is slightly hypointense to isointense on T1. There is a low signal within the acute hematoma on T2-weighting. In the subacute phase (intracellular and extracellular methemoglobin), the signal intensity increases on T1-weighted imaging from slightly hypointense to isointense, to become hyperintense before the end of the subacute period. On T2-weighted images, signal intensity remains low in the early subacute phase and begins to increase towards the end of the subacute period [16].

The most severe complication of conservatively managed traumatic splenic injury is delayed rupture [17]. Patients who are managed conservatively thus require close monitoring and repeated follow-up examinations, which is associated with longer hospitalization time and higher costs of care. Follow-up imaging of spleen lesions has been proposed with various imaging modalities including ultrasound [18], contrast-enhanced ultrasound [19, 20], and contrast-enhanced CT [21, 22]. Interestingly, to the best of our knowledge, MR imaging as an imaging tool for characterization of traumatic parenchymal injury of the spleen has not been reported so far. Our study indicates that indeterminate spleen lesions at primary CT can be further characterized with MR imaging. Beyond that, MR imaging also allowed for depiction of even thin subcapsular hematomas, which have been implicated as an important cause of delayed rupture [17, 23, 24].

In our study population, MR imaging indicating a non-traumatic origin of spleen lesions in nine patients resulted in a

change of management, showing that these patients underwent no further follow-up imaging with any modality in the course of their hospital stay. This is in distinction to the patients with presumably traumatic spleen lesions in whom several subsequent imaging studies were performed. Importantly, patients with presumably non-traumatic spleen lesions according to MR imaging were asymptomatic on clinical follow-up after 2 months.

CT imaging employs ionizing radiation, and it is currently assumed that there exists a dose-dependent risk of developing cancer from radiation for each dose level, without a lower threshold [25]. In addition, radiation risk depends on the age of the irradiated subject, being highest in children and young adults [26]. Ultrasound is non-invasive, widely available, and cost-effective; however, it is highly operator-dependent [18]. In addition, ultrasound is limited in regard to the detection of traumatic parenchymal spleen injury [27]. An alternative could be contrast-enhanced ultrasound, which shows better capabilities for characterization of traumatic injury to parenchymal abdominal organs [19, 20].

Thus, use of MR imaging as a second level modality for characterizing splenic lesions would be advantageous from both the radiation and the operator-dependence perspectives. Of course, contraindications of MR imaging exist; including pacemaker and cochlea implants and claustrophobia of the patient. In addition, MR imaging requires compliant patients being able to follow breath-hold commands during image acquisition which might not be the case in all patients after trauma. In our population, MR imaging was performed between 4 h and 9 days after trauma (median 24 h), when patients were considered to be compliant enough. In addition, total MR examination time was kept short (17 min) for minimizing the risk of artifacts from motion.

The following study limitations must be acknowledged. First, the retrospective nature of our study has inherent shortcomings. Second, our sample size is limited with only 25 patients. Third, CT was obtained only in the portal-venous phase of enhancement, which represents the current standard of care in our institution. An additional arterial phase might have resulted in a better capability of CT for discriminating traumatic from non-traumatic splenic lesions as previously suggested [28]. Thus, using a two-phasic contrast media protocol would have probably resulted in a lower number of indeterminate spleen lesions in our study. Fourth, differences between initial CT and follow-up MR imaging might well be caused by the temporal evolution of parenchymal trauma. This could be particularly true for the thin subcapsular hematomas detected on MR but not on CT images. Finally, our study lacks a gold standard for the diagnosis of traumatic versus non-traumatic spleen lesions in MR imaging. However, surgery with splenectomy and subsequent pathological work-up in patients only for the purpose of a study cannot be considered ethical.

In conclusion, our study introduces MR imaging of the spleen as a potential modality for characterization of indeterminate spleen lesions on primary CT in patients after blunt abdominal trauma. Our initial experience indicates that certain MR imaging features allow for the differentiation between incidental, benign, and traumatic spleen lesions, thus showing potential of MR imaging for an optimized triage of patients with blunt abdominal trauma.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Kailidou E, Pikoulis E, Katsiva V et al (2005) Contrast-enhanced spiral CT evaluation of blunt abdominal trauma. JBR-BTR 88(2):61–65
2. Yao DC, Jeffrey RB Jr, Mirvis SE et al (2002) Using contrast-enhanced helical CT to visualize arterial extravasation after blunt abdominal trauma: incidence and organ distribution. AJR Am J Roentgenol 178(1):17–20
3. Hoff WS, Holevar M, Nagy KK et al (2002) Practice management guidelines for the evaluation of blunt abdominal trauma: the East practice management guidelines work group. J Trauma 53(3):602–615
4. Stedman JM, Franklin JM, Nicholl H, Anderson EM, Moore NR (2014) Splenic parenchymal heterogeneity at dual-bolus single-acquisition CT in polytrauma patients-6-months experience from Oxford, UK. Emerg Radiol
5. Becker CD, Mentha G, Schmidlin F, Terrier F (1998) Blunt abdominal trauma in adults: role of CT in the diagnosis and management of visceral injuries. Part 2: gastrointestinal tract and retroperitoneal organs. Eur Radiol 8(5):772–780
6. Fang JF, Wong YC, Lin BC, Hsu YP, Chen MF (2006) Usefulness of multidetector computed tomography for the initial assessment of blunt abdominal trauma patients. World J Surg 30(2):176–182
7. Raikhlin A, Baerlocher MO, Asch MR, Myers A (2008) Imaging and transcatheter arterial embolization for traumatic splenic injuries: review of the literature. Can J Surg 51(6):464–472
8. van der Vlies CH, Olthof DC, Gaakeer M, Ponsen KJ, van Delden OM, Goslings JC (2011) Changing patterns in diagnostic strategies and the treatment of blunt injury to solid abdominal organs. Int J Emerg Med 4:47
9. Heller MT, Kanal E, Almusa O, et al. (2014) Utility of additional CT examinations driven by completion of a standard trauma imaging protocol in patients transferred for minor trauma. Emerg Radiol
10. Karlo CA, Stolzmann P, Do RK, Alkadhi H (2013) Computed tomography of the spleen: how to interpret the hypodense lesion. Insights Imaging 4(1):65–76
11. Modi S, Gadvi R, Yeo D, Galea-Soler S (2014) Retrospective review of image quality of CT in polytrauma patients: comparison of patients scanned using a scoop stretcher and without a scoop stretcher. Emerg Radiol 21(1):23–27
12. Semelka RC, Martin DR, Balci C, Lance T (2001) Focal liver lesions: comparison of dual-phase CT and multisequence multiplanar MR imaging including dynamic gadolinium enhancement. J Magn Reson Imaging 13(3):397–401
13. Buntain WL, Gould HR, Maull KI (1988) Predictability of splenic salvage by computed tomography. J Trauma 28(1):24–34

14. McCort JJ (1987) Caring for the major trauma victim: the role for radiology. Radiology 163(1):1–9
15. Shuman WP, Ralls PW, Balfe DM et al (2000) Imaging of blunt abdominal trauma. American College of Radiology. ACR Appropriateness Criteria. Radiology 215(Suppl):143–151
16. Bradley WG Jr (1993) MR appearance of hemorrhage in the brain. Radiology 189(1):15–26
17. Cocanour CS, Moore FA, Ware DN, Marvin RG, Clark JM, Duke JH (1998) Delayed complications of nonoperative management of blunt adult splenic trauma. Arch Surg 133(6):619–624, discussion 24–5
18. Andrews MW (2000) Ultrasound of the spleen. World J Surg 24(2): 183–187
19. Poletti PA, Platon A, Becker CD et al (2004) Blunt abdominal trauma: does the use of a second-generation sonographic contrast agent help to detect solid organ injuries? AJR Am J Roentgenol 183(5):1293–1301
20. Valentino M, Serra C, Zironi G, De Luca C, Pavlica P, Barozzi L (2006) Blunt abdominal trauma: emergency contrast-enhanced sonography for detection of solid organ injuries. AJR Am J Roentgenol 186(5):1361–1367
21. Lawson DE, Jacobson JA, Spizarny DL, Pranikoff T (1995) Splenic trauma: value of follow-up CT. Radiology 194(1):97–100
22. Federle MP (1995) Splenic trauma: is follow-up CT of value? Radiology 194(1):23–24
23. Farhat GA, Abdu RA, Vanek VW (1992) Delayed splenic rupture: real or imaginary? Am Surg 58(6):340–345
24. Liu PP, Lee WC, Cheng YF et al (2004) Use of splenic artery embolization as an adjunct to nonsurgical management of blunt splenic injury. J Trauma 56(4):768–772, discussion 73
25. Sodickson A, Baeyens PF, Andriole KP et al (2009) Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. Radiology 251(1):175–184
26. Ware DE, Huda W, Mergo PJ, Litwiller AL (1999) Radiation effective doses to patients undergoing abdominal CT examinations. Radiology 210(3):645–650
27. Poletti PA, Wintermark M, Schnyder P, Becker CD (2002) Traumatic injuries: role of imaging in the management of the polytrauma victim (conservative expectation). Eur Radiol 12(5):969–978
28. Boscak AR, Shanmuganathan K, Mirvis SE, et al. (2013) Optimizing trauma multidetector CT protocol for blunt splenic injury: need for arterial and portal venous phase scans. Radiology