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ABDOMINAL RADIOLOGY

# Blunt abdominal trauma: role of contrast-enhanced ultrasound (CEUS) in the detection and staging of abdominal traumatic lesions compared to US and CE-MDCT

**Barbara Sessa · Margherita Trinci · Stefania Ianniello · Guendalina Menichini · Michele Galluzzo · Vittorio Miele**

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**Abstract**

*Purpose* This study was undertaken to evaluate the accuracy of contrast-enhanced ultrasound (CEUS) in the detection and grading of abdominal traumatic lesions in patients with low-energy isolated abdominal trauma in comparison with baseline ultrasound (US) and contrast-enhanced multidetector computed tomography (CE-MDCT), considered the gold standard.

*Materials and methods* A total of 256 consecutive patients who arrived in our Emergency Department between January 2006 and December 2012 (159 males and 97 females aged 7–82 years; mean age 41 years), with a history of low-energy isolated abdominal trauma were retrospectively analysed. All patients underwent US, CEUS with the use of a second-generation contrast agent (Sonovue, Bracco, Milan, Italy) and MDCT. Sensitivity, specificity, positive and negative predictive values (PPV and NPV) and overall accuracy for the detection of lesions and free peritoneal fluid on US and CEUS, and sensitivity for the grading of lesions on CEUS were calculated compared with the CT findings, in accordance with the American Association for the Surgery of Trauma criteria.

*Results* CE-MDCT identified 84 abdominal traumatic lesions (liver = 28, spleen = 35, kidney = 21) and 45 cases of free intraperitoneal fluid. US depicted 50/84 traumatic lesions and 41/45 cases of free peritoneal fluid; CEUS identified 81/84 traumatic lesions and 41/45 free peritoneal fluid. The sensitivity, specificity, PPV, NPV and overall accuracy for the identification of traumatic abdominal lesions were 59, 99, 98, 83 and 86 %, respectively, for US and 96, 99, 98, 98 and 98 %, respectively, for CEUS. The values for the identification of haemoperitoneum were 91, 99, 95, 98 and 97 %, respectively, for US and 95, 99, 95, 99 and 98 %, respectively, for CEUS. CEUS successfully staged 72/81 traumatic lesions with a sensitivity of 88 %.

*Conclusions* In patients with low-energy isolated abdominal trauma US should be replaced by CEUS as the first-line approach, as it shows a high sensitivity both in lesion detection and grading. CE-MDCT must always be performed in CEUS-positive patients to exclude active bleeding and urinomas.

**Keywords** Traumatic injury · Hematoma · Laceration · Active bleeding · Urinoma · Ultrasound · Contrast-enhanced ultrasound · Second-generation blood-pool contrast agent · Contrast-enhanced multidetector computed tomography

B. Sessa (✉) · M. Trinci · S. Ianniello · G. Menichini · M. Galluzzo · V. Miele
Department of Cardiovascular and Emergency Radiology, San Camillo Hospital, Circonvallazione Gianicolense 87, 00152 Rome, Italy
e-mail: barbara.sessa@tiscali.it

M. Trinci
e-mail: margherita.trinci@libero.it

S. Ianniello
e-mail: stefianni66@gmail.com

G. Menichini
e-mail: guendalina.menichini@gmail.com

M. Galluzzo
e-mail: galluzzom@tiscali.it

V. Miele
e-mail: vittoriomiele@alice.it

## Introduction

Trauma patients involved in a high-energy accident who are in stable condition or whose vital functions have been stabilised are rapidly examined with total-body computed tomography (CT), the most accurate and panoramic imaging tool in the assessment of polytrauma [1].

Abdominal ultrasound (US) performed in the emergency room on unstable patients is termed FAST (focused assessment with sonography for trauma), and is real-time sonographic scan of four regions for the detection of free peritoneal fluid [2].

The management of patients with mild or low-energy trauma is still the subject of controversy; evaluation of the patient's clinical presentation and the mechanism of the injury are fundamental for the decision to immediately perform CT or assess the patient with conventional radiographs, sonography, and clinical observation [3].

Baseline abdominal US is the first step in the protocol in many emergency centres and it is recommended to be performed before the CT study. US is a rapid, repeatable, noninvasive and inexpensive examination that has high sensitivity for the detection of free intra-abdominal fluid but fairly low sensitivity (even below 50 % in the literature) for the detection of abdominal solid organ traumatic lesions [4].

Contrast-enhanced US (CEUS) in traumatic patients has been shown to be more sensitive than US for the detection of solid organ injuries, improving the identification and grading of traumatic abdominal lesions with levels of sensitivity and specificity similar to CT (up to 95 % in the literature) [2–4]. The aim of this study was to evaluate the accuracy of CEUS in the detection and staging of abdominal traumatic lesions in patients with low-energy isolated abdominal trauma in comparison with baseline US and contrast-enhanced multidetector CT (CE-MDCT), considered the gold standard.

## Materials and methods

### Patients

We performed a retrospective review of a case series that included 256 consecutive patients who arrived at our Emergency Department between January 2006 and December 2012 (159 males, 97 females, age range 7–82 years, mean age 41 years), with a history of low-energy isolated abdominal trauma and in stable haemodynamic condition (pulse pressure >90 mmHg, heart rate <100 beats per minute, respiratory rate <20 respirations per minute), categorised "yellow" or "green" using the START triage acuity scale. All patients underwent US, CEUS with the use of a second-generation contrast agent (Sonovue, Bracco) and MDCT. The major causes of blunt abdominal trauma are reported in Table 1. Written informed consent was obtained from all the patients or from their relatives in the case of minors.

**Table 1** Major causes of blunt abdominal trauma

| Cause | No. of patients | % |
|---|---|---|
| Motorcycle and car crashes | 140 | 55 |
| Working trauma | 54 | 21 |
| Accidental trauma | 41 | 16 |
| Sport trauma | 21 | 8 |

### Examination technique

Conventional US and CEUS examinations were performed with a Siemens Acuson Sequoia 512 system (Siemens Medical Systems, Forchheim, Germany) using a curved-array 4 MHz multi-frequency probe.

Baseline abdominal US was followed by CEUS performed in the same session with an intravenous bolus injection of a second-generation blood-pool contrast agent (Sonovue, Bracco) consisting of stabilised microbubbles of sulphur hexafluoride gas covered by a stabilising phospholipidic membrane. Asymmetric oscillation of the microbubbles produces a returning signal (echo) containing harmonics. The Sequoia system is equipped with contrast-pulse sequencing (CPS) software which detects the fundamental nonlinear response of the microbubbles; continuous low-mechanical-index (MI 0.15–0.19) real-time tissue harmonic imaging (Cadence) allows real-time grey-scale imaging [5, 6].

A total of 4.8 mL of Sonovue, fractionated into two 2.4 mL doses, was administered through an 18-gauge needle inserted in an antecubital vein, followed by 5–10 mL of saline solution [7, 8]. Immediately after the first bolus the right-sided organs (right kidney and liver) were explored for 1–3 min. With the second dose the left-side organs (left kidney and spleen) were focused on for a further 3–4 min [9]. All CEUS examinations were performed by highly experienced radiologists, with at least 5 years' experience in emergency radiology and with specific expertise in trauma imaging (US, CEUS, MDCT).

All patients underwent CE-MDCT examination within 1 h after CEUS, using a standard arterial and venous protocol, with a 16-detector-row CT scanner (16 LightSpeed, GE Healthcare, USA). No patient received oral contrast medium and all underwent a pre-contrast acquisition series. A volume of nonionic contrast medium of 100–150 mL was injected at a rate of 2–4 mL/s through an 18–20-gauge angiography catheter. A delay ranging from 40 to 50 s was used for the arterial phase and from 80 to 100 s for the second acquisition; in the presence of collections, a late-phase study (at 3–15 min) was performed to identify any active bleeding or urinoma.

Data collection

In this study we analysed only traumatic parenchymal injuries of liver, spleen and kidneys; no pancreatic lesions and no mesenteric or bowel lesions were depicted.

Positive findings on US were solid organ injury and peritoneal fluid. On US a parenchymal traumatic lesion was depicted as an intraparenchymal hyper- or hypoechoic area or distortion of the normal echoic structure [9, 10].

On CEUS examination positive findings were parenchymal lesions, intraparenchymal or subcapsular haematoma, active blush and peritoneal fluid. Traumatic injuries were identified as a perfusion defect represented by a hypoechoic area with ill- or well-defined margins with or without interruption of the organ profile. Lacerations can appear as a hypoechoic linear lesion, usually oriented perpendicular to the organ surface (Fig. 1b, 2b, 4b). Haematomas are depicted as nonenhancing areas (Fig. 1b, 3b). Focal extravasation of microbubbles outside a lacerated organ suggests active bleeding (Fig. 6c).

CEUS and CT grading of lesion severity were based on the American Association for the Surgery of Trauma (AAST) classification [11, 12].

Statistical analysis

Contrast-enhanced CT was considered the gold standard technique. Sensitivity, specificity, positive and negative predictive values and overall accuracy were calculated for the number of lesions and the presence of free peritoneal fluid on US and CEUS, compared with the CT findings. The sensitivity of CEUS for the grading of lesions and for the identification of active bleeding was calculated on the basis of CT findings.

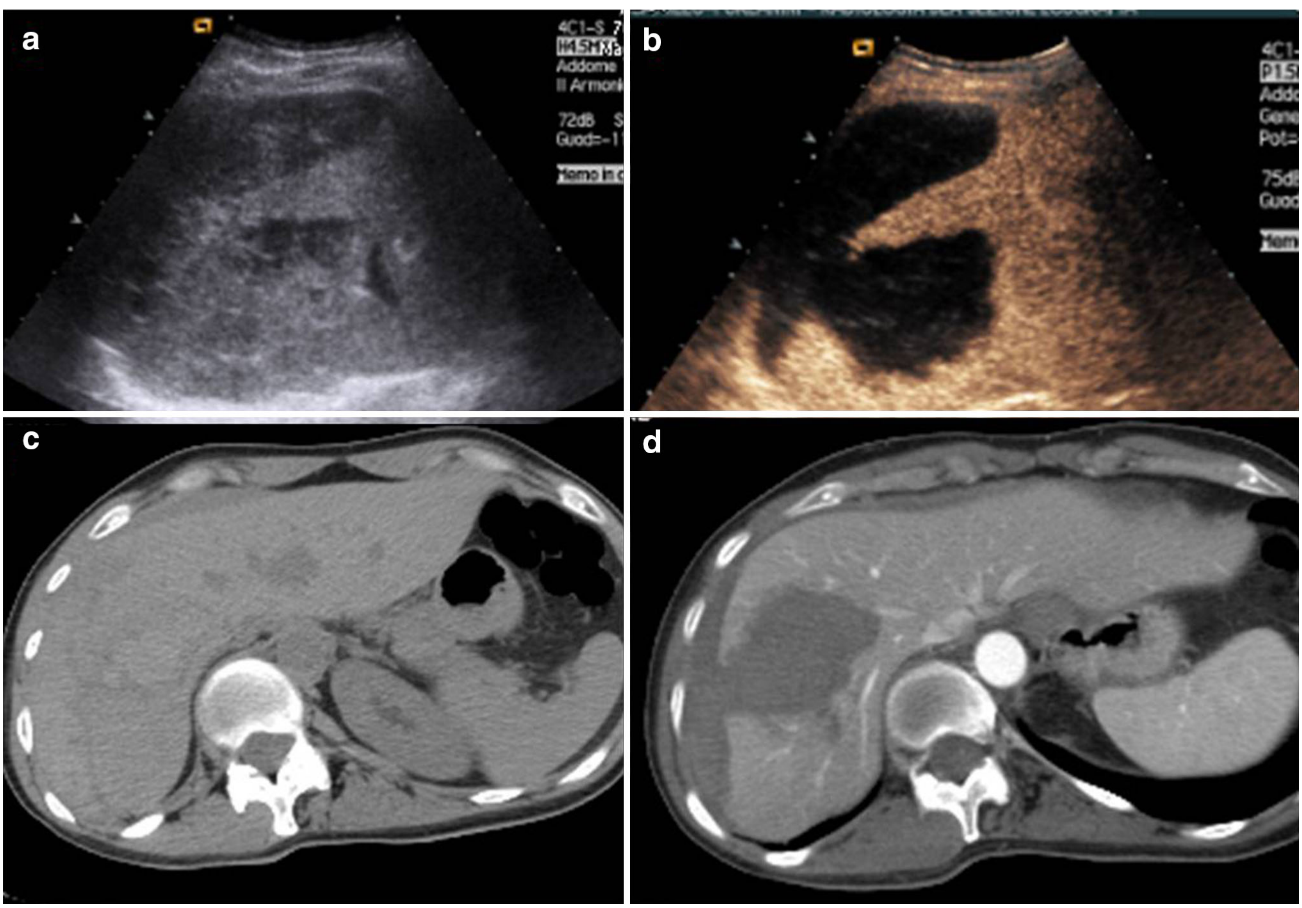


**Fig. 1** 41-year-old female involved in a motorcycle crash: **a** ultrasound (US) examination shows an inhomogeneous hypoechoic parenchymal area of the liver and a subcapsular haematoma; **b** contrast-enhanced US (CEUS) scan shows grade III traumatic laceration on hepatic segment VII with a parenchymal and subcapsular haematoma; **c** axial multidetector computed tomography (MDCT) examination shows the hyperdense subcapsular and intraparenchymal haematoma; **d** CE-MDTC scan shows identical findings to CEUS

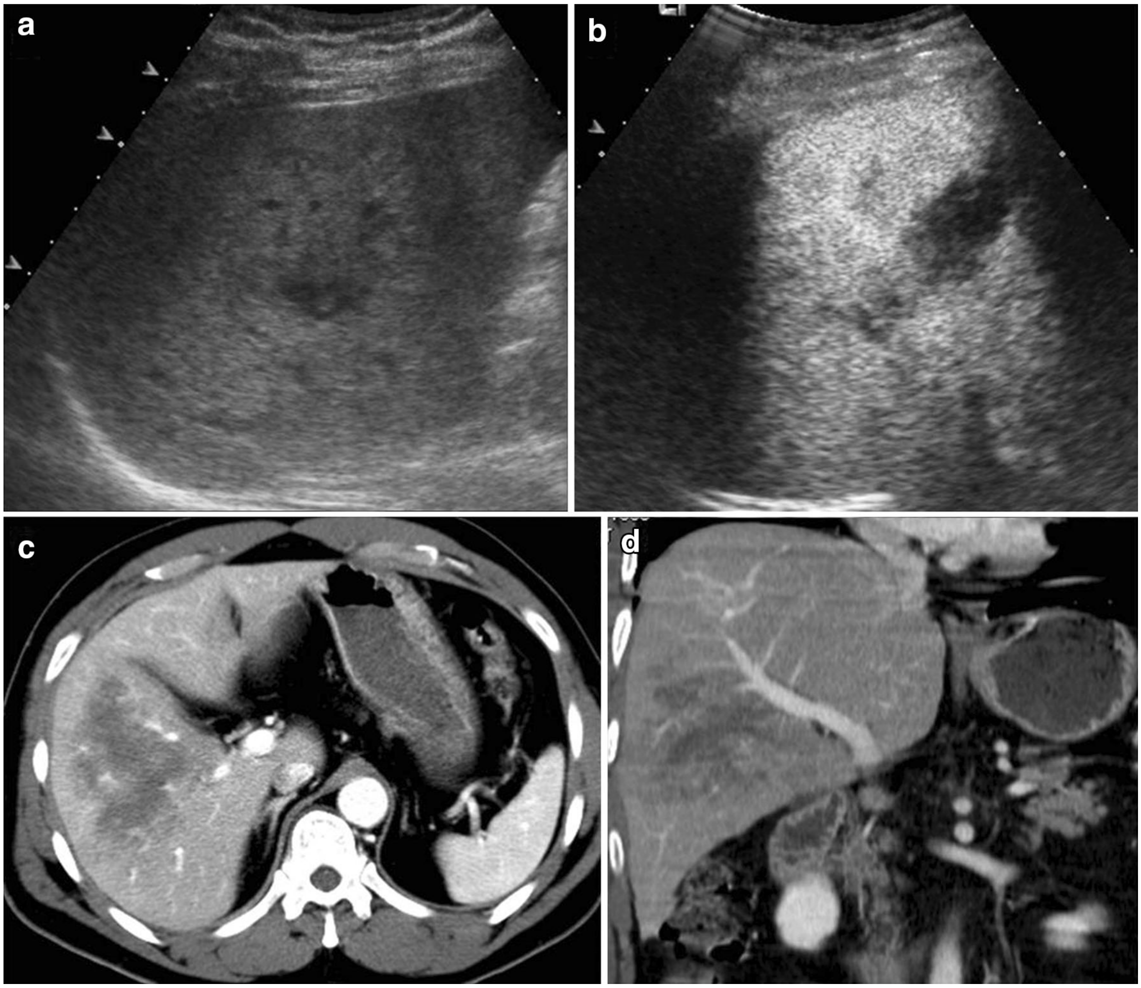


**Fig. 2** 49-year-old male involved in a motorcycle vs car accident: **a** US image shows a fine distortion of the normal echoic structure on hepatic segment V; **b** CEUS scan shows a hypoechoic grade III traumatic lesion on segment V; axial (**c**) and coronal (**d**) CE-MDCT scans show identical findings to CEUS

## Results

In the 256 patients included in the study, CE-MDCT identified 84 (32 %) abdominal positive traumatic findings of the liver ($n = 28$), spleen ($n = 35$) and kidney ($n = 21$). In 45/256 patients CE-MDCT depicted free intraperitoneal fluid.

On the basis of the CE-MDCT findings, considered as the reference standard, we analysed the capacity of US and CEUS to identify the traumatic lesions. US depicted 50/84 traumatic injuries (liver = 17/28, spleen = 20/35, kidney = 13/21) and free fluid in 41/45 positive patients. US yielded one false positive in the identification of traumatic injuries (one lesion of the liver segment VIII which turned out to be a focal liver lesion on CT) and two false positives in the detection of haemoperitoneum (two young women with a small amount of free fluid in the pouch of Douglas). CEUS identified 81/84 traumatic injuries (liver = 27/28, spleen = 34/35, kidney = 20/21) (Table 2). CEUS yielded three false negative results (one liver lesion <1 cm in segment VIII, one splenic lesion <1 cm and one small contusion of the left kidney) and one false positive result (a hypoechoic lesion of the spleen which turned out to be an ischaemic area on CT). CEUS depicted 43/45 cases of free peritoneal fluid (the same as US). The number of true positives, false positives, true negatives and false negatives yielded by US and CEUS compared with MDCT in the detection of traumatic injuries and free peritoneal fluid are reported in Tables 3 and 4. The sensitivity, specificity, positive and negative predictive values and accuracy for the identification of traumatic abdominal lesions were, respectively, 59, 99, 98, 83 and 86 % for US and 96, 99, 98, 98 and 98 %, respectively, for CEUS (Table 5). The values for the identification of haemoperitoneum were 91, 99, 95, 98 and 97 % for US and 95, 99, 95, 99 and 98 % for CEUS (Table 6).

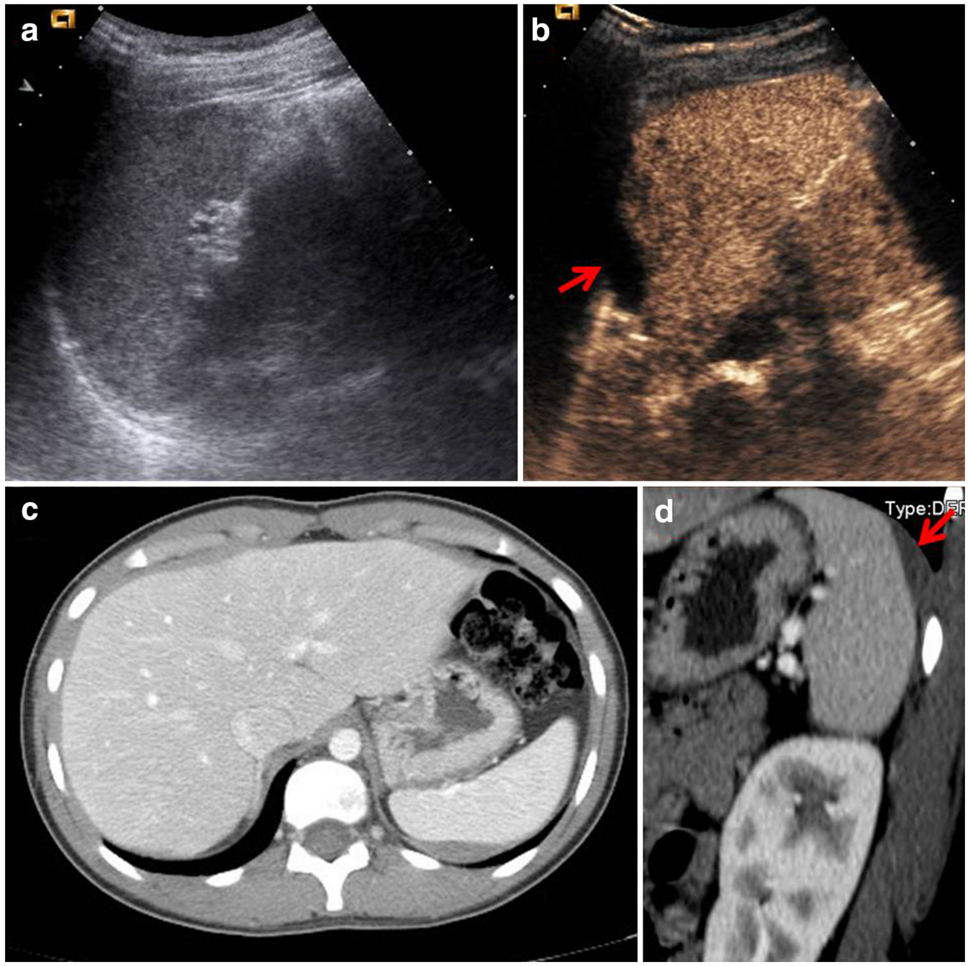


**Fig. 3** 20-year-old female involved in a motorcycle crash: **a** baseline US does not show any parenchymal splenic lesion or haematoma; **b** CEUS reveals a little subcapsular haematoma (*red arrow*); **c**, **d** axial and sagittal CE-MDCT scans show similar findings to CEUS (*red arrow*)

**Table 2** Number of lesions identified on US, CEUS and CE-MDCT

| | US | CEUS | CE-MDTC |
|---|---|---|---|
| Liver | 17 | 27 | 28 |
| Spleen | 20 | 34 | 35 |
| Kidney | 13 | 20 | 21 |

**Table 3** Number of true positives (TP), true negatives (TN), false positives (FP), false negatives (FN) on US, CEUS and CE-MDCT, respectively, in the identification of the number of lesions

| | TP | TN | FP | FN |
|---|---|---|---|---|
| MDCT | 84 | 172 | 0 | 0 |
| US | 50 | 171 | 1 | 34 |
| CEUS | 81 | 171 | 1 | 3 |

As for the grading of traumatic lesions according to the AAST criteria [11, 12], MDCT depicted no grade IV–V lesions of the liver and no grade V lesions of the spleen or kidney. Liver lesions ($n = 28$) were classified as: grade I ($n = 7$), grade II ($n = 8$), grade III ($n = 10$) and grade IV ($n = 3$). Splenic lesions ($n = 35$) were classified as: grade I ($n = 6$), grade II ($n = 10$), grade III ($n = 13$), grade IV ($n = 6$). Kidney lesions ($n = 21$) were classified as: grade

**Table 4** Number of true positives (TP), true negatives (TN), false positives (FP), false negatives (FN) on US, CEUS and CE-MDCT, respectively, in the identification of free intraperitoneal fluid

| | VP | VN | FP | FN |
|---|---|---|---|---|
| MDCT | 45 | 209 | 2 | 0 |
| US | 41 | 209 | 2 | 4 |
| CEUS | 43 | 209 | 2 | 2 |

**Table 5** Values of sensitivity (SE), specificity (SP), positive predictive value (PPV), negative predictive value (NPV) and accuracy (ACC) of US, CEUS and CE-MDCT, respectively, in the identification of the number of lesions

| | SE (%) | SP (%) | PPV (%) | NPV (%) | ACC (%) |
|---|---|---|---|---|---|
| MDCT | 100 | 100 | 100 | 100 | 100 |
| US | 59 | 99 | 98 | 83 | 86 |
| CEUS | 96 | 99 | 98 | 98 | 98 |

**Table 6** Values of sensitivity (SE), specificity (SP), positive predictive value (PPV), negative predictive value (NPV) and accuracy (ACC) of US, CEUS and CE-MDCT, respectively, in the identification of free intraperitoneal fluid

| | SE (%) | SP (%) | PPV (%) | NPV (%) | ACC (%) |
|---|---|---|---|---|---|
| MDCT | 100 | 99 | 95 | 100 | 99 |
| US | 91 | 99 | 95 | 98 | 97 |
| CEUS | 95 | 99 | 95 | 99 | 98 |

I ($n = 3$), grade II ($n = 6$), grade III ($n = 8$), grade IV ($n = 4$).

On the basis of these CT values CEUS successfully staged 72/81 recognised traumatic lesions: 23/27 liver lesions (Figs. 1, 2, 6), 30/34 splenic lesions (Figs. 3, 4) and 19/20 kidney lesions (Fig. 5) with a sensitivity of 88 % (Table 7). Nine lesions were understaged at CEUS examination: in four cases CEUS understaged minor traumatic injuries that needed conservative, nonsurgical management, in four cases CEUS did not demonstrate the presence of active bleeding and in one it failed to depict a lesion of the urinary tract (Fig. 7). The four understaged lesions were distributed as follows: two liver lesions (one CEUS grade I was grade II on CE-MDCT; one CEUS grade II was grade III on CE-MDCT) and two splenic lesions (two CEUS grade I were grade II on CE-MDCT).

In the identification of active bleeding CE-MDCT depicted ten cases, six from the liver (one of which with capsule rupture and blushing into the peritoneal cavity) and four from the spleen. CEUS identified 6/10 cases of contrast pooling, four from the liver lacerations (Fig. 6) and two from the spleen; in 4/10 cases CEUS did not recognise

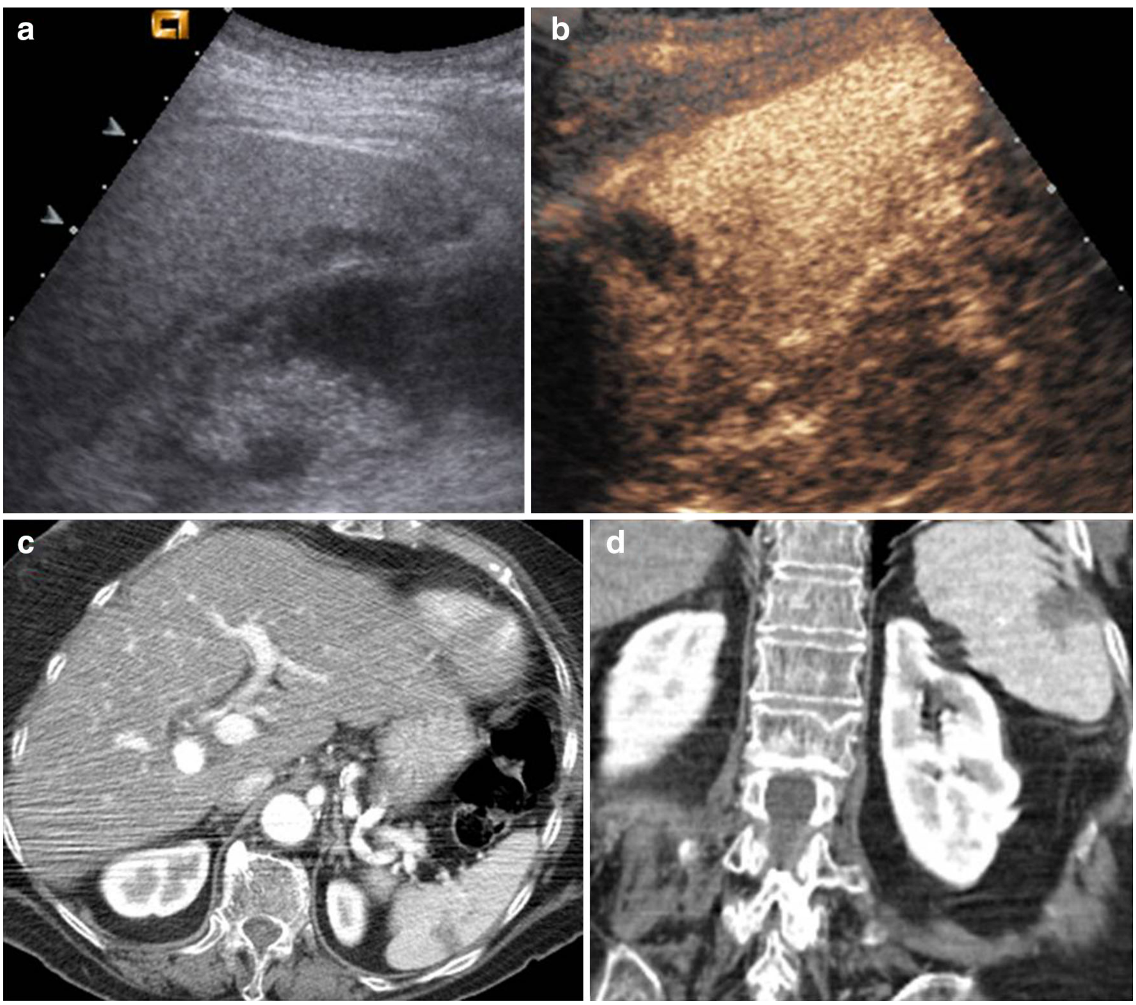


**Fig. 4** 78-year-old female involved in a domestic accident: **a** difficult baseline US in noncooperative patient does not show any parenchymal splenic lesion but only a small amount of perisplenic fluid; **b** CEUS examination shows a hypoechoic grade II traumatic laceration involving the capsular surface of the spleen; **c**, **d** axial CE-MDCT and coronal multiplanar reconstruction (MPR) confirm the CEUS findings

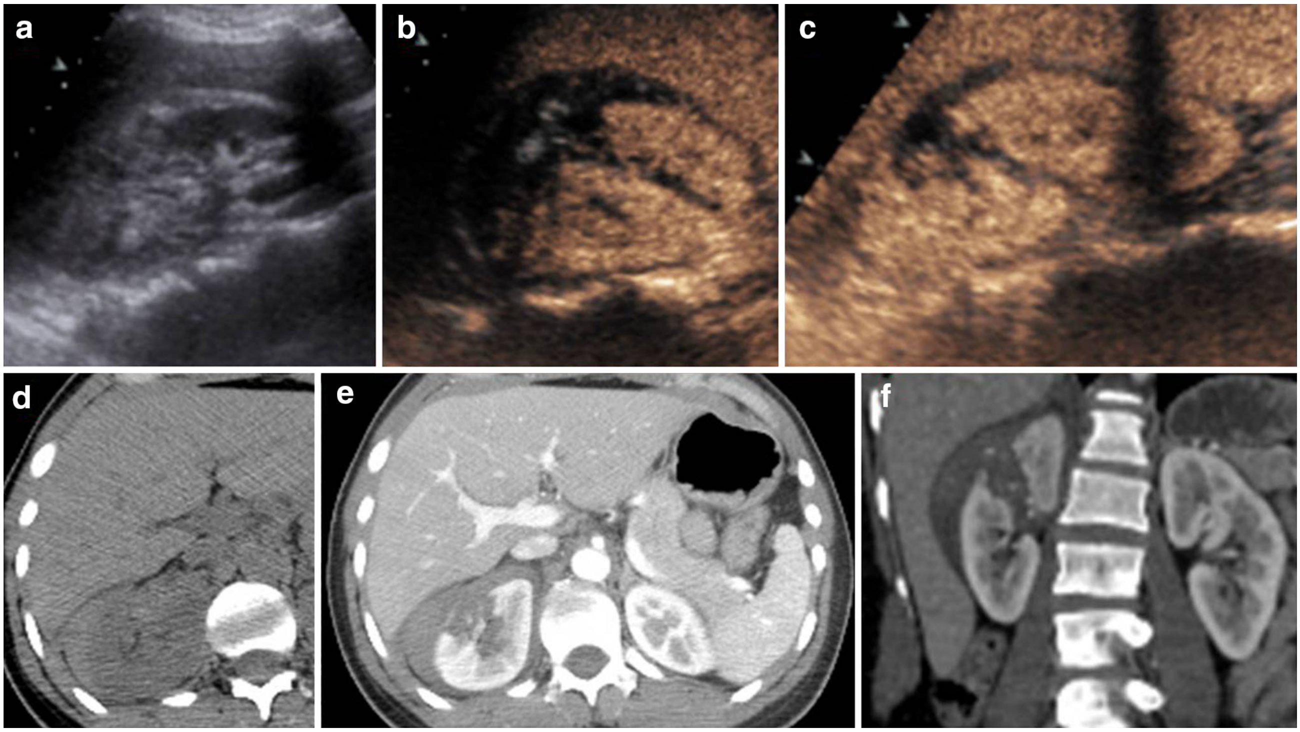


**Fig. 5** 40-year-old male involved a motorcycle vs car crash: **a** longitudinal US only shows a cortical hyperechoic inhomogeneity at the proximal third of the right kidney; perirenal hyperechoic fluid; **b**, **c** axial and longitudinal CEUS scans show a parenchymal fracture and the presence of perirenal fluid; **d** axial MDCT scan shows hyperdense perirenal fluid; **e**, **f** axial and coronal CE-MDCT images in the venous phase show the renal fracture with perirenal fluid

**Table 7** Grading of traumatic lesions on CEUS and CE-MDCT according to the AAST criteria

| | Grade | CEUS | CE-MDTC |
|---|---|---|---|
| Liver | I | 7 | 7 |
| | II | 10 | 8 |
| | III | 7 | 10 |
| | IV | 3 | 3 |
| Spleen | I | 7 | 6 |
| | II | 10 | 10 |
| | III | 11 | 13 |
| | IV | 6 | 6 |
| Kidney | I | 2 | 3 |
| | II | 6 | 6 |
| | III | 9 | 8 |
| | IV | 3 | 4 |

the presence of active bleeding, in two liver lesions and in two splenic injuries which were understaged in CEUS (grade II on CEUS and grade III on CE-MDCT), with 60 % sensitivity of CEUS in the detection of contrast-agent extravasation as specific sign of active bleeding. Finally, in one case CEUS did not demonstrate a lesion of the urinary tract, understaging a grade IV kidney lesion on CE-MDCT (Fig. 7).

## Discussion

For polytrauma patients most trauma centres adopt a standardised protocol in accordance with the advanced trauma life support (ATLS) recommendations: for the initial evaluation of all trauma patients involved in a high-energy accident or with loss of consciousness some radiographic examinations and an abdominal US (focused assessment with sonography for trauma, FAST) are systematically performed. When the vital functions of the victims have been stabilised they rapidly undergo a total-body CT examination [1]. This is a rapid, complete, and reproducible imaging study which allows rapid detection of all the possible body injuries in a single examination (head, spine, chest, abdomen, pelvis and extremities), with the possibility to promptly detect prognostic negative factors (such as active bleeding) and so to direct the polytrauma victim to conservative or surgical management.

In haemodynamically unstable patients the FAST examination can be done in the emergency setting without interrupting resuscitation manoeuvres and has a reported sensitivity for the detection of intraperitoneal free fluid between 63 and 96 % [1]; its major limitations are poor sensitivity in the direct detection of solid abdominal organ lesions and in the visualisation of haemoretroperitoneum.

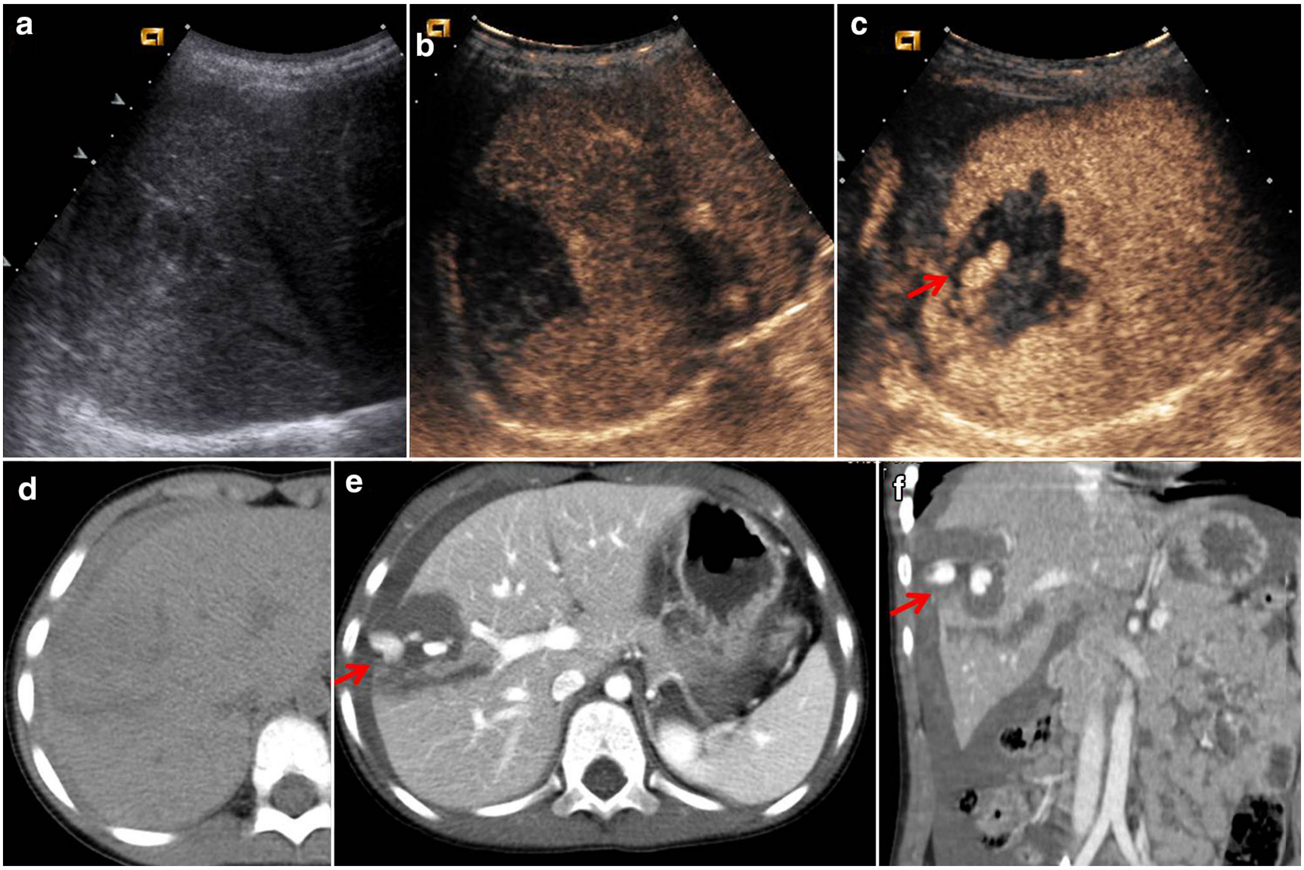


**Fig. 6** 8-year-old male involved in a sport accident: **a** baseline US shows an inhomogeneous hypoechoic parenchymal area on hepatic segment VII; **b** this CEUS scan shows a hypoechoic grade IV laceration and parenchymal haematoma involving the capsule; **c** this CEUS image clearly depicts the active bleeding with interruption of the organ profile (*red arrow*); **d** axial MDCT shows the parenchymal and perihepatic hyperdense haematoma; **e**, **f** axial and coronal CE-MDCT scans confirm the CEUS findings with evidence of capsule rupture and blushing out in the peritoneal cavity (*red arrow*)

In patients with mild or low-energy trauma, there is a large spectrum of possible imaging modalities: CT, conventional radiography, or US can be performed on the basis of clinical presentation and laboratory parameters. In the diagnostic assessment of trauma patients abdominal US is frequently used as a first-step modality for its safety, repeatability and noninvasiveness, and ability to determine the need for abdominal CT. Systematic use of CT after low-energy trauma, in fact, may lead to inappropriate delays in patient care, is costly, and involves radiation exposure to a young patient population [1].

The sensitivity of US for the detection of free abdominal fluid varied from 63 to 99 % but the reported sensitivity for the detection of solid organ lesions is quite low, below 50 % [2–4]. This is an important drawback especially in the subset of patients in whom parenchymal trauma is not associated with free peritoneal fluid. Peritoneal fluid can be related to trauma but it can also be present in other conditions such as ovulation, ascites etc.

The introduction of second-generation contrast agents into clinical practice has improved US accuracy in detecting parenchymal injury after blunt abdominal trauma, increasing the lesion identification rate with sensitivity values in the definition of lesion size, relationship with the capsule and vessel peduncle similar to those of CT [2–4, 6–14]. CEUS can additionally identify findings undetectable at conventional US, such as infarcts and contrast extravasation [5, 15–17].

In our study only parenchymal injuries of the liver, spleen or kidneys were evaluated; no pancreatic lesions were depicted. US identified 50 traumatic injuries of the 84 depicted on CT, with a sensitivity of 59 %; the sensitivity of US in the detection of free peritoneal fluid was higher (91 %). The use of contrast medium greatly improved the number of detected lesions but also the quality of findings, with a better definition of lesion extension, margins and relationship with the capsule and vessels. No mesenteric or bowel traumatic lesions were found; in these cases CEUS could give false negative results. CEUS correctly identified 81/84 traumatic lesions depicted on CE-MDCT, increasing the value of sensitivity for the detection of traumatic abdominal injuries from 59 % of US to 96 %. The three

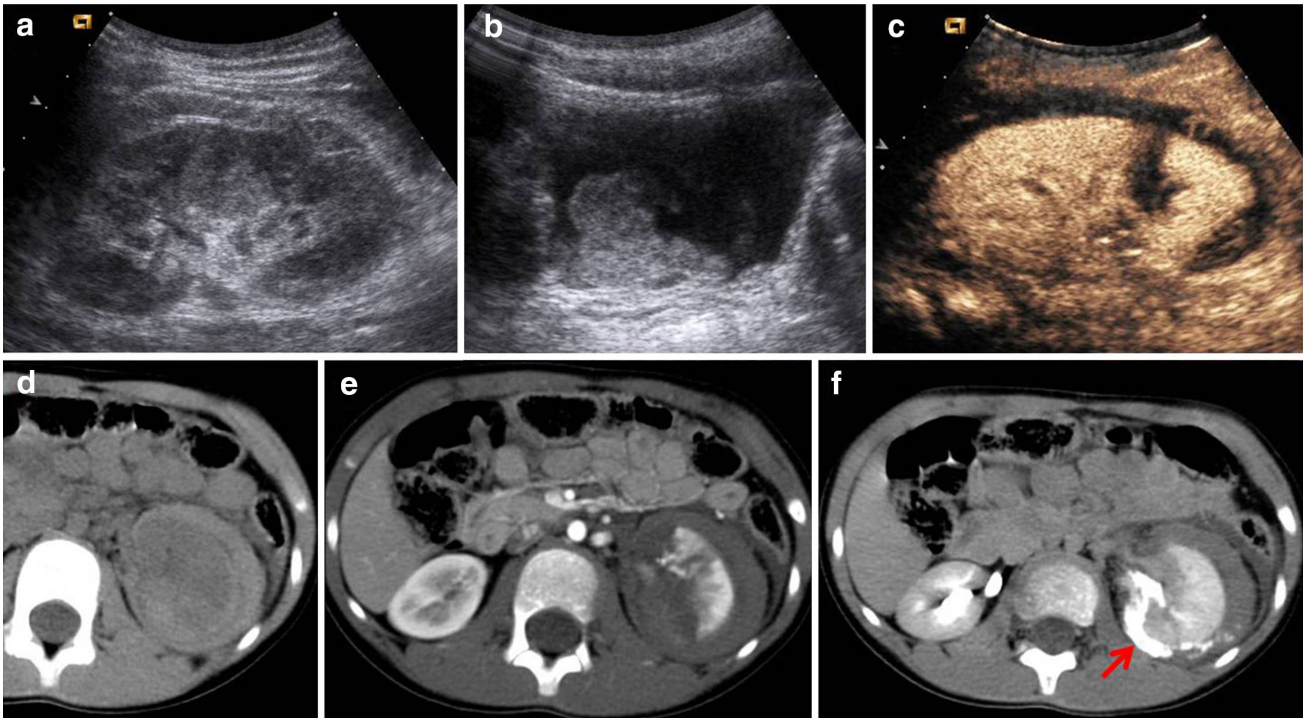


**Fig. 7** 7-year-old female involved in an accidental trauma during outdoor game: **a** longitudinal US does not show any lesion but only a fine cortical parenchymal inhomogeneity of the left kidney with perirenal fluid; **b** blood clot in the bladder, indirect sign of a traumatic lesion of the collector system; **c** CEUS very well depicts the renal fracture and the presence of perirenal fluid; **d** axial MDCT shows a hyperdense perirenal collection; **e** axial CE-MDCT in the venous phase depicts the renal fracture and confirms the perirenal fluid that in the late phase (**f**) turned out to be a urinoma (*red arrow*)

false negative findings on CEUS were all grade I lesions, due to minor injuries, without relevant consequences for patient management and prognosis. CEUS yielded one false positive finding which turned out to be an ischaemic lesion of the spleen on MDCT. In lesion grading CEUS correctly staged 72 of the 81 detected lesions using the AAST criteria, with a sensitivity of 88 %: nine lesions were understaged on CEUS (four of the liver, four of the spleen and one of the kidneys). In four cases, CEUS only understaged minor traumatic injuries that required a conservative, nonsurgical management, but in four cases CEUS understaged traumatic lesions because of failure to identify the presence of contrast pooling (in 2/6 liver lacerations and in 2/4 splenic injuries); finally in one case CEUS failed to detect a lesion to the urinary tract (understaging a grade IV kidney lesion on CE-MDCT).

Therefore, in our experience the main limitations of CEUS are its poor visualisation of active bleeding and its inability to demonstrate lesions to the urinary tract. Indeed, in our series CEUS did not recognise the presence of active bleeding in 40 % of cases (4/10 lesions) with a sensitivity of 60 %; in one case CEUS did not demonstrate lesions to the urinary tract. The reported sensitivity of CEUS in the detection of contrast pooling varies in the literature [15–17]; a recent study [5] reported a sensitivity of 72.4 % in the identification of sites of active bleeding with a compared sensitivity of contrast-enhanced CT of 81.2 %.

In patients with low-energy isolated abdominal trauma, a greater use of CEUS may allow us to reduce observation time or CT use in patients who are negative at baseline US, thereby decreasing the number of contrast-enhanced CT examinations [18–22]. In our experience, when positive findings are demonstrated on CEUS, CT becomes necessary to identify any negative prognostic factors such as active bleeding or lesions to the urinary tract.

## Conclusions

In patients with low-energy isolated abdominal trauma, conventional US has low sensitivity in the identification of organ injuries and should, therefore, be replaced by CEUS as the first-line approach. CEUS has shown a high sensitivity both in the detection and grading of traumatic lesions.

Patients with negative CEUS may be discharged, monitoring the clinical and laboratory findings, without undergoing CT examination because only lower grade injuries could be missed. CEUS in fact can clearly demonstrate most of the aspects relevant for management with a high sensitivity in both detection and grading. A more controversial aspect is the sensitivity of CEUS in the detection of contrast-medium extravasation, as well as its inability to depict lesions to the urinary tract, findings which are clearly depicted on CT. Patients with positive CEUS should always undergo CE-MDCT to exclude any negative prognostic factors such as active bleeding, rupture of urinary tract or additional lesions.

**Conflict of interest** The authors declare no conflict of interest.

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