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Role of Contrast Enhanced Ultrasound (CEUS) in the Paediatric Population with Blunt Abdominal Trauma: A Prospective Study from a Single Center Experience for Paediatric Blunt Abdominal Trauma

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ABSTRACT

Aim: *The aim of our study is to evaluate the diagnostic ability of contrast-enhanced ultrasonography (CEUS) in pediatric population with history of blunt abdominal trauma (BAT).*

Materials and methods: *In an eight-year period (1/2012-1/2020), fifty-nine children (4-14 years old) were transferred to the Emergency Department with referred BAT. The initial imaging method was ultrasound scan*

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(US). Thirty-two children were discharged in good condition 24 hours after their admission. The remaining 27, who had moderate to severe injuries and according to their laboratory tests and US results, were evaluated with CEUS and contrast-enhanced computed tomography (CECT).

Results: *Five children were confirmed with splenic injury, two with liver lacerations, one with liver lacerations and right kidney contusion, while in nineteen, no visceral pathology was found by US, CEUS and CECT. The CEUS and CECT were in complete agreement. On the contrary, unenhanced-US showed free peritoneal fluid in eleven children and possible parenchymal lesions in two children. In two of the patients with negative US-study, splenic contusions in CECT and CEUS were revealed. The CEUS study was also used as a follow-up method. Among the 27 patients, there were no adverse reactions from the CEUS contrast agent either at one-week and six-month follow-up, or after one-year period.*

Conclusion: *Contrast-enhanced ultrasonography is an effective, easily performed, low cost and radiation free imaging method. It is ideal for both initial and follow up evaluation of trauma and thus, we encourage its usage in paediatric BAT cases.*

Keywords: abdominal injury, BAT, CECT, CEUS, child.

Abbreviations:
BAT=blunt abdominal trauma
CECT=contrast-enhanced ultrasonography
CEUS=contrast-enhanced ultrasonography
ED=Emergency department
e-FAST=extended-FAST
FAST=Focused assessment with sonography for trauma
US=ultrasound scan

INTRODUCTION

Trauma is the most frequent cause of death in the population younger than 45 years. In children, the abdomen is the third most common site of injury after head and extremities and it is well known that a prompt diagnosis can prevent patients from severe consequences (1, 2). Focused assessment with sonography for trauma (FAST) or e-FAST (extended-FAST) is usually the initial imaging method for evaluation, especially for haemodynamically unstable patients who sustained blunt abdominal trauma. Extended-FAST is performed to detect haemothorax, pneumothorax, and haemoperitoneum, but it has major limitations and a poor sensitivity (41%–44%) in the direct depiction of solid abdominal organ lesions (3).

In haemodynamically stable patients with high-energy trauma, or when the haemodynamic stabilization occurs, contrast-enhanced computed tomography (CECT) is performed; CECT is the gold standard in the evaluation of injured patients. Unfortunately, CECT has the disadvantage of radiation exposure (4). In our study, all children were tested for renal function before iodine contrast agent administration, even those with negative history for renal impairment. Furthermore, the overall rule in our everyday practice can be summarized as follows: FAST is the first diagnostic step, particularly in unstable children, while in stable children conventional US examination is a standard procedure, before additional imaging, either CECT or CEUS.

Contrast-enhanced ultrasonography is a relatively novel, radiation-free method alternative to CECT with the potential to identify abdominal solid organs lacerations but its use is off-label in children (the contrast agent SonoVue® has recently been approved by the FDA under the name of Lumason® to be used in hepatic investigations in adults and children). Contrast agents are neither nephro-, hepato- or cardio-toxic and do not require testing of renal function prior to examination, which is necessary with other contrast media (for CT). Furthermore, the use of CEUS in children is supported by clinical experience (5, 6).

For children with blunt abdominal trauma, physical examination plus FAST and CEUS, as needed, seems to have reasonable sensitivity, specificity and accuracy in detecting intra-abdominal injuries and may reduce the need for CT scans (3). This present study aims to estimate and underline the usefulness of CEUS in the evaluation of paediatric blunt abdominal trauma. ❑

MATERIALS AND METHODS

The present study was conducted during an eight-year period, from January 2012 to Ja-

nuary 2020, in the Emergency Department of our University Hospital. Patients enrolled in the study included all children up to 14-year-old who were admitted for referred BAT and had positive clinical, laboratory and/or US findings. Research was performed in accordance with the Declaration of Helsinki. The research was approved by the ethical and deontology committee (Protocol number: 21234) of the General University Hospital of Alexandroupolis, Greece, and the science committee of our hospital. Informed consent was obtained from all participants and/or their legal guardians.

All imaging methods were performed by two radiologists (one pediatric radiologist and one general) and the CEUS scans were followed by CECT within 30 minutes. All parents were informed about the imaging method (CEUS) and signed a consent form (deemed "off-label" method). Moreover, parents/guardians were informed that the components (microbubbles phoospholipides) of the administered formulation exhaled in 10 minutes and metabolized in a day (respectively). Even so, their children would be monitored for possible side effects after CEUS for about a year period (to exclude any other cause, eg, mental, emotional, etc.). All CEUS scans were compared with CECT results, with CECT being the gold standard in the evaluation of injured patients (4).

During the eight-year study period, 59 children (38 boys and 21 girls) aged between 4 and 14 years were referred to the Emergency Department of our University Hospital with reported abdominal injury. All patients initially underwent conventional US that followed FAST. Thirty-two of them (21 boys and 11 girls) with minor injuries, normal physical examination, negative US and laboratory results within normal limits were discharged after 24 hours of observation without undergoing further investigation. The remaining 27 patients, which formed our study population, suffered from more severe injuries with positive clinical, laboratory and/or US findings (Table 1).

Ultrasonography and contrast-enhanced ultrasonography

Patients initially underwent FAST examination, and in suspicious and stable patients CEUS and CECT was performed. The CEUS-exam started typically from the kidneys, continued with the liver and ended in the spleen (Figure 1). In cases

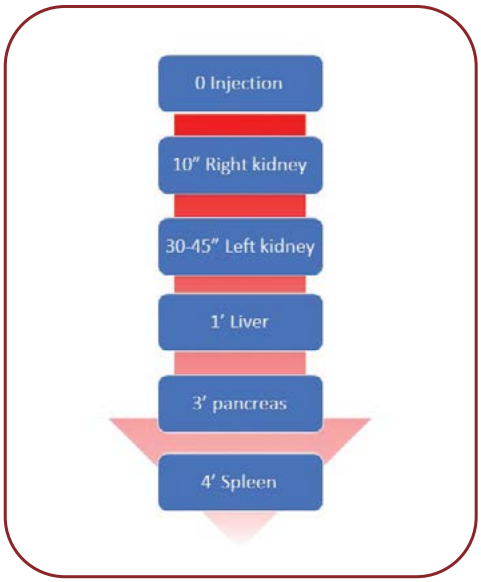

FIGURE 1. CEUS: time of organ visualization after injection of intravenous contrast agent

with not an appropriate imaging effect, a resumption of the method with second intravenous injection was followed (in our study nine from twenty-seven small patients). The overall time needed was up to five minutes for each contrast agent injection.

The CEUS procedure requires contrast medium injection and US machine suitable to CEUS software. All CEUS studies were performed with a 5-1 MHz convex array transducer in a Philips iU22 ultrasound machine. SonoVueTM (Bracco, Milano, Italy) was used by us as contrast media. SonoVueTM is an agent made of microbubbles stabilized by phospholipids and containing Sulphur hexafluoride (SF6), an innocuous gas. The microbubbles have a diameter ranged from 1 micron to 7 microns (1 micron is equal to 0.0001 cm). This contrast medium is blood-pool agent with a non-linear reverberation on US. The microbubbles remain intravascular and produce a non-linear harmonic response that can be separated from the tissue signal using contrast harmonic US (equipment's software). Our dosage schemes for SonoVueTM were adjusted to 0.03 mL *per* kg (0.03 mL/kg) *per* every intravenous injection, with a maximum of 2.4 mL *per* single bolus injection (7, 8). Generally, SonoVueTM suspension was administered by syringe bolus using an existing peripheral vein. This was followed by a 5 mL normal saline flush. Vital signs were monitored at two minute-intervals during

the CEUS-study and also 30 minutes and one hour after completion of contrast injection for possible adverse reaction symptoms. This monitoring was completed with the recording of other side effects such as nausea, vomiting, dizziness, etc.

On baseline US if lesions were visible, they were recognized as a hypoechoic or hyperechoic alteration(s) within the organ. On CEUS, when lesions were present in a solid organ they were clearly visible in all patients. The lesions were depicted as a perfusion defect (demarcated hypoechoic area compared to the adjacent parenchyma) with ill-defined or well-defined margins with or without interruption of the organ profile and margins. If lack of perfusion of a part(s) of the organ was present, an arterial lesion was suspected, while the presence of microbubbles (reflections) outside of the lacerated organ was defined as an active bleeding.

Approximately the whole CEUS-exam were captured as video movie, while selective images have been also recorded. CECT was performed within 30 minutes with intravenous injection of a nonionic contrast agent (1.5 mL/kg) and during the arterial phase, the venous phase and a late-

	Age	Sex	US/FAST	CEUS	CECT
1	14	male	+ (fluid)	Liver laceration	Liver laceration
2	9	female	+ (fluid)	L lacer + R kidney	L lacer + R kidney
3	13	male	+ (fluid)	spleen contusion	spleen contusion
4	11	female	-	spleen rapture	spleen rapture
5	8	female	+ (fluid) / spleen suspicion	-	-
6	11	male	+ (fluid)	-	-
7	14	female	+ (focal liver hypoattenuation)	spleen rapture	spleen rapture
8	14	male	-	spleen contusion	spleen contusion
9	14	male	+ (fluid)	spleen contusion	spleen contusion
10	14	female	+ (fluid) / liver suspicion	-	-
11	9	male	+ (focal liver hypoattenuation)	Liver laceration	Liver laceration
12	8	female	-	-	-
13	4	male	-	-	-
14	12	male	-	-	-
15	11	male	-	-	-
16	13	male	-	-	-
17	8	female	-	-	-
18	13	female	-	-	-
19	12	male	-	-	-
20	14	male	-	-	-
21	13	female	-	-	-
22	8	male	-	-	-
23	4	female	-	-	-
24	12	male	-	-	-
25	11	female	-	-	-
26	13	male	-	-	-
27	8	male	-	-	-

FAST=focused assessment with sonography for trauma; CEUS=contrast enhanced ultrasound; CECT=contrast-enhanced CT; -=negative results.

TABLE 1. Demographics and imaging findings

phase study (5-15 min), with the latter performed if fluid collections were revealed to identify more accurately any active bleeding and/or urinoma.

Data were analyzed using Microsoft Excel. The sensitivity, specificity, positive and negative predictive value of conventional US and CEUS were determined compared to CECT. ❑

RESULTS

The mean age of our study population was 10.93±2.9 (mean ±SD) years. Seventeen of all subjects were boys (63%) and ten girls (37%) (Table 1). The mechanisms of trauma in these children were 19 bicycle crashes (one bicycle *vs* car), four car accidents (one car *vs* pedestrian), three jumps from a high wall and one (1) slip in the bathtub. With the suspicion of visceral organ injury, all patients underwent CEUS-scan, followed by CECT before their hospitalization (Table 1).

All children were in stable haemodynamic condition. No visceral pathology was found in 19 out of the 27 children who were included in our study. The presence of fluid in baseline US was accepted as indirect evidence of visceral injury. According to that, US has a high sensitivity and specificity (80% and 84.21%, respectively). On the other hand, the presence on US of hyperechoic lesion in visceral parenchyma has a low sensitivity but a high specificity for visceral injury (25% and 94.12%, respectively).

In five children (three boys and two girls with an average age of 13.2 years), splenic injury (three contusions and two ruptures) was found. The mechanisms of accident were bicycle crash for two boys, jump of a high wall for one boy and one girl, and slip in the bathtub for one girl. Liver laceration was revealed in two boys and in one girl both liver laceration and right kidney contusion were depicted. The two boys (14- and 9-year-old) with liver lacerations were involved in car accident and finally the nine-year-old girl was involved in a bicycle collision with car. CECT depicted the same lesions with CEUS. Contrarily, conventional US showed free peritoneal fluid in 11 patients and possible solid organ rupture

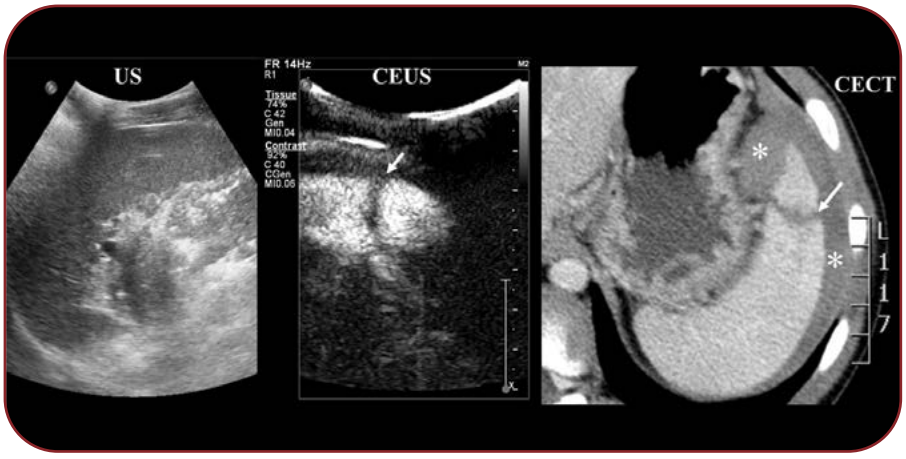

FIGURE 2. Patient No 4: US reveals normal spleen appearance with no peri-splenic fluid unlike the CEUS and CECT which depict splenic rapture (arrows) and an amount of peri-splenic fluid (stars).

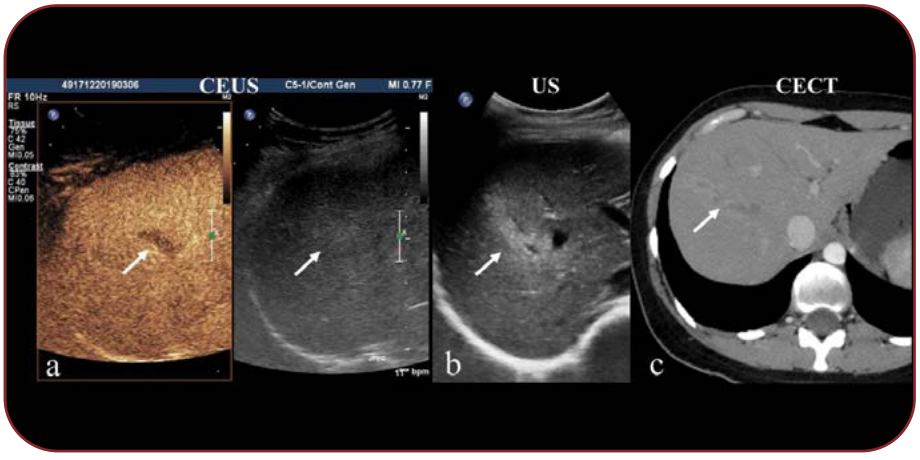

FIGURE 3. Patient No 11: A linear focal hyperattenuation on US confirmed as liver laceration both on CEUS and CECT (arrows). a) CEUS; «side by side images»; the B-Mode image (right image) is not sufficient for diagnostic purpose due to low mechanical index (MI) in order to prevent microbubbles; b) initial ultrasound (US), c) CECT

(spleen and liver) in two (patients 5 and 10). In those two patients (patients 5 and 10) CEUS and CECT was administrated, but no evidence of pathology was found. Even though 18 children (patients 4, 8 and 12-27) had negative US, CECT and CEUS was conducted due to the severity of the injury mechanism and the positive clinical and/or laboratory results (Figure 2). In two children (patients 4 and 8) there were spleen contusions in CECT and CEUS (Figure 3). The examination with CEUS has a duration of less than ten minutes, it does not require sedation and has a lower cost than CECT scan. Patients were monitored for a year, the agent was well tolerated, and no adverse reactions were referred on either short term (10 minutes and one day) or long term (up to one year). ❑

DISCUSSION

Trauma is the major cause of morbidity and mortality in pediatric population and the abdomen is the second most common site of injury (1). The main focus of this study was the validation of CEUS in comparison with CT in order to identify possible visceral injuries in paediatric cases of blunt abdominal trauma (BAT). According to our results, CEUS revealed the same outcomes with CECT. Regarding negatives and positives findings CEUS and CECT demonstrated similar results. On the contrary, US had two false negatives (7.41%) (patients 4 and 8) and three false positives (11.11%) (patients 5, 6 and 10). Even though patients 4, 8 and 12-27 had negative US, we performed CEUS and CECT because they had positive laboratory (first discovered-low hematocrit) or clinical results (*eg*, abdominal pain). Although it seemed like we overreacted, we were able to find two false negative US results (patients 4 and 8). Both pathologies (spleen rapture and spleen contusion) are medical emergencies. A misdiagnose in those patients might have been proven fatal.

Diagnostic imaging plays an important role in the evaluation of trauma in children. The small body and low amount of fat in children make them excellent candidates for conventional US, which is widely used both for diagnostic and monitoring for many pediatric diseases. However, the use of US in paediatric trauma is doubted. Many reports mention that conventional US has a low sensitivity and is unreliable as a diagnostic tool (9-12).

Magnetic resonance imaging (MRI) in children has many advantages but also some disadvantages, including the need for sedation or general anesthesia in younger children, long exam duration and use of gadolinium-based contrast agents. Furthermore, in pediatric population, visceral organ bleeding tends to be self-limited despite the severity of trauma, because there is a major vasoconstrictive response due to smaller blood vessels; therefore, a non-operative strategy is highly followed in the management of traumatized pediatric patients. Hence, after the initial evaluation (CECT and CEUS) and during follow-up, the injured child must be monitored according to radioprotection criteria (ALARA principles). Under these circumstances, CEUS can play a major role as a follow-up tool (11-13) for solid organ injuries in children who have suffered low- to moderate-energy blunt traumatic events (14).

An important limitation of our study is the small number of subjects, and thus, its limited ability to determine diagnostic accuracy in regard to specific organ injuries such as kidneys, liver, pancreas, and duodenum. Of course, there are papers which speculate that injuries to the gastrointestinal tract, including intestinal or mesenteric injury, are not depicted easily on CEUS (15). However, when an intramural duodenal hematoma is suspected, an intestinal wall thickening or an echogenic lesion along the duodenal convexity, with no enhancement on CEUS-scan referred as typical imaging findings (16).

On other hand, the sample size of splenic injuries was more frequent, giving the possibility of drawing safer conclusions. It is known that spleen is a well vascularized organ, which in children it is not protected from the rib cage like in adults because it is bigger. This is the reason why it is often involved in blunt abdominal trauma, with a frequency of 46.7% of the cases both as isolated or multiorgan lesions (17, 18). Furthermore, splenic parenchymal lesions are extremely indistinguishable and thus, it is very difficult to recognize them, especially when perisplenic fluid is not present (19). These lesions are better visualized on delayed CEUS evaluation (120 to 240 seconds after contrast medium injection) (20).

Active bleeding is distinguishable on CEUS and this method could replace US in patients with low to mild energy abdominal trauma as the first diagnostic approach, because it has a high sensitivity in lesion detection and grading. However, CECT might be performed in patients with positive CEUS results to exclude urinomas and/or active bleeding (21).

In hemodynamically stable trauma patients, paediatric patients included, CT is the imaging technique of choice to evaluate abdominal trauma. However, the benefit of avoiding ionizing radiation is far more important in children. Also, someone must keep in mind that the intravenous contrast used for CT is associated with up to a 4% incidence of adverse reactions (22).

There is a wide spectrum of imaging modalities when we face a mild or low-energy trauma patient such as conventional radiography, CT or US. The appropriate choice is based on clinical presentation and laboratory findings. Ultrasound evaluation is used as a first-step modality due to its well-known advantages (portable, safe, repeatable, noninvasive) and its ability to indicate the necessity of abdominal CECT. In these patients, the use of CECT routinely as the initial imaging modality might lead to unnecessary delays in patient management and involves radiation exposure to paediatric population (23, 24). ❑

CONCLUSIONS

Contrast-enhanced ultrasound is an imaging modality that can be used to diagnose the possibility of abdominal solid organ injury in paediatric blunt abdominal trauma without exposing children to ionizing radiation. Of course, further clinical trials may aid in defining the ultimate utility of CEUS in paediatric BAT patients. ❑

Conflicts of interest: none declared.

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Data availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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