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Post-traumatic liver and splenic pseudoaneurysms in children: Diagnosis, management, and follow-up screening using contrast enhanced ultrasound (CEUS)

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ABSTRACT

Background: Pseudoaneurysm (PA) formation following blunt and penetrating abdominal trauma is a recognized complication in solid organ injury, usually diagnosed by contrast-enhanced CT (CECT) imaging. Delayed rupture is a potentially life-threatening event, although its frequency is not known in pediatric trauma. Contrast enhanced ultrasound (CEUS) is a novel radiation-free alternative to CECT with the potential to identify PA.

Methods: A retrospective review of consecutive cases of significant liver and splenic injuries admitted to single institution (tertiary and quaternary referrals) over more than a 12 year period was performed. From 2011, CEUS was performed routinely postinjury (5–10 days) using SonoVue™ as contrast. Initially, CECT and CEUS were performed in tandem to ensure accurate correlation.

Results: From January 2002–December 2014, 101 (73 M) children [median age was 14.2 (1.3–18) years] with liver and splenic injuries were admitted. Injuries included: liver [n = 57, grade 3 (1–5)], splenic [n = 35, grade 3 (1–5)], and combined liver/spleen [n = 8, (1–4)]. Median Injury Severity Score (ISS) was 13 (2–72). The predominant mechanisms of injury were blunt trauma n = 73 (72%) and penetrating trauma n = 28 (28%). Seventeen children (17%) developed PA. Six children became symptomatic (35%), and five went on to have embolization [at 7 (3–11) days]. These were detected by CECT (n = 4) and CEUS (n = 2). Eleven children remained asymptomatic [detected by CECT (n = 8) and CEUS (n = 3) at median 5 (4–8) days]. One underwent embolization owing to evidence of interval bleeding.

Sensitivity of CEUS at detection of PA was 83%, with specificity of 92% (PPV = 71%, NPV = 96%). There was no association between grade of injury and presence of PA in either liver or splenic trauma (P = 0.4), nor was there an association between size of PA and symptoms (P = 0.68). Children sustaining splenic PA were significantly younger than those with hepatic PA (P = 0.03). Follow-up imaging confirmed resolution of PA in 16 cases. One child was lost to follow-up.

Conclusions: The incidence of PA is higher than previously reported in the pediatric literature (<5%). Postinjury imaging appears mandatory, and CEUS appears to be highly sensitive and specific for diagnosis and follow-up.

Pseudoaneurysms (PAs) develop following injury to an arterial wall resulting in leakage of blood usually into a contained cavity. Communication with the arterial lumen is maintained but this creates a high pressure cavity with risk of life-threatening rupture [1]. They are a rare but recognized complication following blunt and penetrating abdominal trauma and are usually seen within the liver (often in association with a bile leak) and the spleen [2–5]. Hepatic PA has also been reported following percutaneous liver biopsy, gallstone disease, pancreatitis and surgery [1,6,7].

A recent pediatric study reports incidences of 1.7% (hepatic) and 5.4% (splenic) PA using color Doppler ultrasound (US) screening. However, their follow-up rate was low at 61% and probably represents an underestimate of the true incidence [8]. Guidelines exist for the suggested management of abdominal trauma in children, however there is a lack of consensus over the necessity of follow-up screening and timing. It is further complicated by the lack of understanding of the natural history of traumatic hepatic and splenic PA which are often asymptomatic and of delayed presentation [2,8–10].

Contrast enhanced ultrasound (CEUS) is a novel radiation-free alternative to contrast enhanced computed tomography (CECT) with the potential to identify PA. The technique was pioneered in children in our institution initially assessing focal liver lesions [11]. Its use in blunt abdominal trauma in children was first described in 2008 by

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Valentino et al. [12] and its use as a screening tool to identify traumatic PA (often with a delayed presentation) in adult patients pioneered in 2013 by Poletti et al. [13]. They quoted a 75% sensitivity and 100% specificity, compared to CECT controls in a cohort of 63 adults.

The aims of this study were to identify the true incidence of hepatic and splenic PAs in the setting of a pediatric major trauma center and to describe the symptoms, complications and management of PA in that population using CEUS as the follow-up screening modality of choice.

1. Methods

Our patients were identified using a prospectively maintained database (aged <18 years) of hepatic and splenic trauma more than a 12 year period (January 2002–December 2014). Our center functions as a level 3 major trauma center and provides tertiary pediatric surgery and quaternary pediatric hepatobiliary surgical services.

A biphasic CECT examination was performed on admission in all cases where intraabdominal injury was suspected (mechanism of injury/ clinical suspicion). Grade of injury was ascertained in accordance with the American Association for the Surgery of Trauma Organ Injury Scale [14]. According to our local protocols, CECT was repeated in grade III and above on days 5 to 10 postinjury.

From 2011, with the emergence of CEUS all children irrespective of grade of injuries underwent a CEUS as follow-up screening days 5–10 postinjury and weekly if required thereafter to ensure PA resolution. All imaging was performed by consultant radiologists (AD, MES, PSS). During the learning curve CEUS was performed in tandem with CECT imaging to ensure diagnostic agreement.

A CEUS examination was performed employing a low mechanical index (MI) technique (Cadence Contrast Pulse Sequencing, CPS™, Siemens, Mountain View, CA) and SonoVue™ (Bracco SpA, Milan, Italy) as microbubble contrast material following the normal departmental protocol for a CEUS examination of the liver (bolus of 1.2–2.4 mL of SonoVue™).

Follow-up CECT was performed to identify cause of symptoms in cases where children appeared symptomatic prior to routine screening. Criteria for embolization in our institution depend on factors anecdotally felt to increase the risk of rupture; all peripheral splenic PA were embolized and hepatic PAs were embolized if ≥10 mm or if associated with a bile leak.

Retrospective review of medical notes identified demographics, mechanism of injury and the Injury Severity Score (ISS). Initial management, length of stay, follow-up imaging and outcome were also collected.

Continuous data are reported as median (range). Categorical data were analyzed using Chi square or Fisher tests while continuous data were compared using nonparametric tests as appropriate using GraphPad Prism 5 software (San Diego, CA, USA). A P value of <0.05 was regarded as significant.

2. Results

Overall, 101 children were admitted with abdominal trauma in this 12 year period. Of these, 57 had isolated hepatic injuries, 35 isolated splenic and 8 children had combined hepatic and splenic injuries (all defined by admission CECT). Median age was 14.2 (1.3–17.9) years (Table 1). Of the 101 patients blunt abdominal trauma was the predominant mechanism of injury (n = 72, 72%), including road traffic collision (n = 25, 25%), fall from height (n = 25, 25%), handlebar injury (n = 18, 18%), horse kick (n = 3, 3%) and crush injury (n = 1, 1%). All but one child had a biphasic abdominal CECT as their initial radiological investigation on admission. This single patient developed abdominal pain day 5 postadmission and a hepatic injury was detected on CEUS.

2.1. Management

71 (70%) of children were managed conservatively. Laparotomy was undertaken in n = 16 (16%) for the following principle reasons: continued acute bleeding (hepatic n = 5, splenectomy n = 3), pneumoperitoneum on CECT (n = 5), delayed laparotomy for evacuation and washout of hematoma (n = 2) and washout for combined hemoperitoneum and biloma (n = 1). Thirteen children underwent embolization of which six were for acute bleeding at presentation and seven were delayed for PA [15]. Nine children underwent ERCP and stenting for bile leaks.

2.2. Follow-up imaging

Of the 71 children treated conservatively, n = 62 (87%) underwent routine follow-up imaging to look for the presence of a pseudoaneurysm between days 5 and 10 postinjury. Of the 9 who did not undergo imaging, one did not survive to this point owing to massive head injury, 8 had grade 1 injuries (all these patients were treated prior to 2011 when our screening protocol changed).

45 children had CECT as their primary follow-up imaging for PA at a median of 7 (1–11) days postinjury. This includes CEUS as primary investigation (n = 31) at 5 (2–12) days and unenhanced USS (n = 14) at 11 (1–87) days. One PA was picked up on CECT after CEUS was unable to visualize the area in question. However CEUS was able to identify that 2 children actually had congenital vascular malformations rather than PA as an adjunct to CECT imaging.

2.3. Pseudoaneurysms

In total, 17 (17%) children developed traumatic pseudoaneurysms.

Hepatic PA occurred in 14 (25% of all those with hepatic injury). These were predominantly associated with grades III (40%) and IV (33%) injuries. Six (40%) children became symptomatic with evidence of worsening abdominal pain, hemodynamic instability or an acute drop in hemoglobin of which 5 were embolised acutely at a median of 7 (3–11) days postinjury and one was monitored closely (no active bleeding on CEUS) and PA subsequently resolved. One further child was embolised as they met institutional criteria, despite remaining asymptomatic. Seven children with asymptomatic PA were actively monitored as inpatients until thrombosis or resolution was documented on CECT (n = 3) unenhanced USS (n = 1) (before introduction of CEUS in 2011) and CEUS (n = 3) [median 13 (10–18) days].

Three (9% of splenic injury cohort) children developed splenic pseudoaneurysms (Fig. 1). The median injury grade was 3 (2–4). All three remained asymptomatic and were identified by routine CEUS on day 5 of admission. None met criteria for embolization and were actively monitored until CEUS confirmed resolution of PA with thrombus [8 (7–40) days].

Table 1
Patient demographics.

Total	Age (years)	Sex (m)	ISS[a]	Liver Injury and Grade	Splenic Injury and Grade	Combined Liver and Spleen and Grade	Conservative Management (n)	LOS[b] (days)
n = 101	14.2 (1.3–18)	73%	13 (2–72)	n = 57 3 (1–5)	n =35 3 (1–5)	n = 8 3 (1–4)	n = 71	10 (3–146)

[a] ISS — Injury Severity Score.
[b] LOS — length of stay.

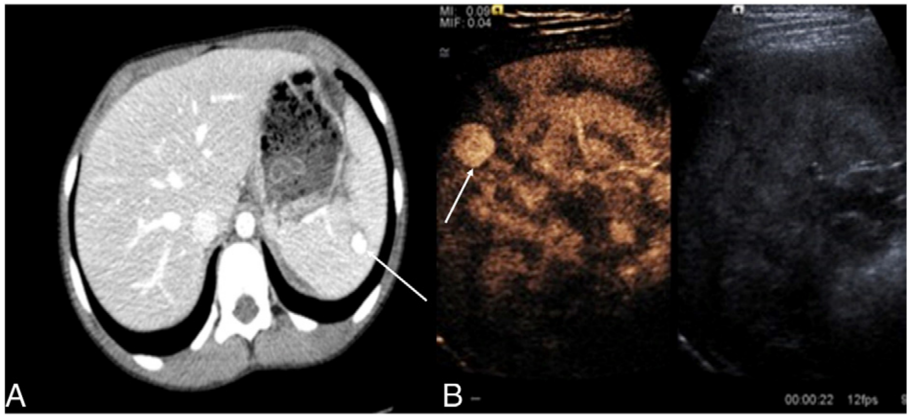

Fig. 1. (A) Contrast enhanced CT of splenic PA (indicated by arrow). (B) A split screen technique using low mechanical index imaging with the CEUS image displaying the splenic PA (indicated by arrow). The right hand image displays the B-mode ultrasound appearances at the site of investigation.

The calculated sensitivity of CEUS for detection of PA (using the CECT examination as standard) was 83%, with a specificity of 92% (PPV = 71%, NPV = 96%) (Table 2).

There was no association between grade of injury and presence of PA in either liver or splenic trauma (P = 0.4) nor association between size of PA and symptoms (P = 0.68) (Fig. 2). Children sustaining splenic PA appeared to be younger than those with hepatic PA (P = 0.03) (Fig. 3). There is no correlation between severity of trauma (ISS) and PA formation (P = 0.88) (Fig. 4).

2.4. Outcome

Median length of stay was 10 days (3–146) for all patients. There were three mortalities secondary to other injuries. Follow-up imaging confirmed resolution of PA in 16 cases however one patient was lost to follow-up. Of those whom underwent embolisation for pseudoaneurysm, no complications were reported.

3. Discussion

Post-traumatic hepatic and splenic PAs in children have up until recently not been highlighted or emphasized as significant complications following abdominal trauma. This may be because of a truly low incidence or more probably the lack of appropriate imaging to identify these potential life-threatening complications.

Our series of CT-defined pediatric abdominal trauma shows an overall incidence of PA formation of 17% predominantly involving the liver rather than the spleen. More importantly, just less than half of those in the liver cohort became symptomatic at approximately one week postinjury. This is a much higher incidence than reported in a series of 362 children from Vancouver, Canada [8] where only 1.7% of liver injuries and 5.4% of spleen injuries developed PA. They used color Doppler US rather than CEUS to screen for PA and had a much lower proportion that were followed up (61%). Intervention was required in a much higher proportion, with 33% of splenic PAs requiring embolisation; two because of failure to thrombose after observation and one for actual rupture on day 6 leading to emergency laparotomy. In distinction, none of the splenic PAs in our study came to intervention but we found that patients with splenic PA were significantly younger than those sustaining hepatic PA. This may simply be reflective of the small numbers or perhaps splenic PAs run a more benign course in the younger patient having a tendency to spontaneous thrombosis given enough time. All three hepatic PAs in the Canadian study required intervention, two of which were symptomatic from rupture in the second week postinjury with life threatening hemorrhage.

Nonoperative management of blunt abdominal trauma is now well established in children, with published guidelines for intervention in those isolated hepatic and splenic injury [2,9,10]. More contentious issues however surround the need for inpatient hospital stay and the role of screening for complications. For instance, based upon the experience in 856 children managed in 32 North American centers, the APSA trauma committee in a report [10] recommended no more than 5 days in hospital, with no postinjury follow-up screening for asymptomatic patients sustaining grades I–IV hepatic/splenic injuries. However, <50% of their subjects were followed up so it is difficult to draw a real conclusion with respect to postinjury sequelae or complications particularly PA formation. The largest adult series reviewed 530 patients with nonoperative management of abdominal trauma. They report a 100% follow-up rate with CECT however 'most scans were performed on days 2–3 postadmission.' They recommend that follow-up imaging should be reserved for symptomatic patients [16]. However, our data suggest that PA may not have formed or become symptomatic by this point. They also neglected to provide any data on readmission rate or follow-up. Sudden acute rupture of a PA is a well-recognized clinical scenario following an asymptomatic course [17]. Thus we have a real concern that absence of secondary screening imaging and short

Table 2
Sensitivity and specificity of CEUS scans to detect PA following hepatic and splenic trauma.

	CT Positive	CT Negative
CEUS Positive	5	2
CEUS Negative	1	23

N.B. sensitivity = 83%, specificity 92% PPV = 71%, NPV = 96%.

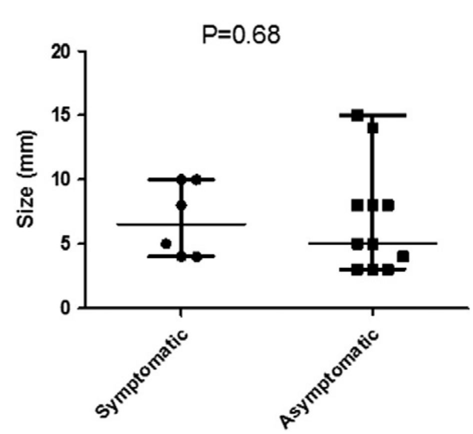

Fig. 2. Comparison between size of pseudoaneurysm (in mm) and presence (n = 6) or absence (n = 11) of symptoms.

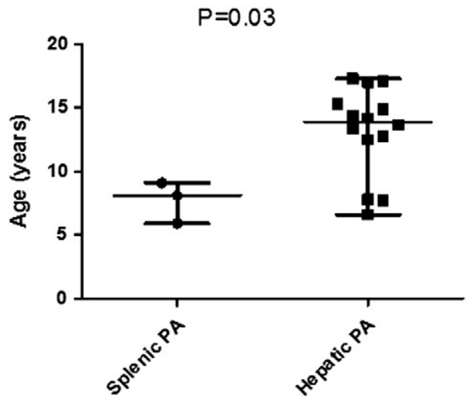

Fig. 3. Comparison between splenic (n=3) and hepatic (n=14) pseudoaneurysm and age at presentation (years) (P = 0.03).

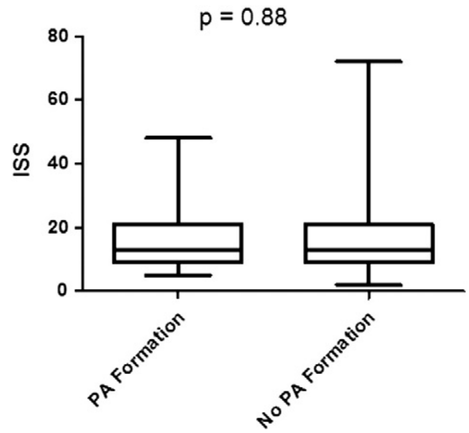

Fig. 4. Injury Severity Score (ISS) in those developing pseudoaneurysm (n = 17) and others (n = 84).

length of stay will put lives in danger — as shown to be the case in three of our children with PA detected postday 5.

A more recent review of 259 conservatively managed adults with liver trauma from Copenhagen, Denmark came to a similar conclusion that screening saved lives [18]. In their series, 73% underwent follow-up imaging using predominantly CECT imaging. This identified seven PAs (overall incidence 4%) and of these, two were symptomatic requiring transfusion and all seven underwent embolization. As with our data they found no correlation between high grade injury and the risk of PA, with three found in grade 2 liver injuries.

CEUS is an effective imaging modality in assessing PA formation in children. In the hands of an experienced operator, it is able to identify PA < 5 mm in any location within the liver or spleen where color Doppler and conventional ultrasound alone would have difficulty. Using a second generation contrast agent, a dynamic scan of the hepatic and splenic vasculature can be obtained without the risks of radiation exposure in children or nephrotoxic intravenous contrast and can therefore be safely performed in cases of concomitant renal trauma where there may be concerns over renal function.

Furthermore, CEUS is used as follow-up screening to ensure PA resolution when certainly the radiation dose of and iodinated contrast burden of repeated CECT imaging would not be acceptable. This series is limited owing to the small number of independent CEUS identified PA. This may be because of a learning curve since its introduction in pediatric trauma patients in 2011. However, with its highly sensitive and versatile applications CEUS will be used more independently and possibly as a first-line admission imaging tool in selected trauma cases.

The incidence of PA is significantly higher than previously reported in the pediatric literature and postinjury imaging therefore appears mandatory in all grades of injury, although CEUS is still relatively novel and we believe that it has a real use and value as a sensitive and specific screening tool for diagnosis and follow-up of hepatic and splenic pseudoaneurysm. Its use as a first-line imaging modality in selected cases is yet to be established.

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