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CHILD ABUSE IMAGING

Macrocephaly and subdural collections

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Abstract
Enlarged subarachnoid spaces are a common finding in infants and young children imaged for macrocephaly or an enlarging head circumference, and benign enlargement of the subarachnoid spaces is often diagnosed. Infrequently, presumed "spontaneous" subdural hemorrhages or subdural collections might complicate these enlarged subarachnoid spaces. Children with large bilateral subdural collections might also present for imaging with macrocephaly. Each scenario potentially raises concerns for prior injury because subdural hemorrhage is a frequent finding in children with abusive head trauma.

Keywords Abusive head trauma · Benign enlargement of the subarachnoid spaces · Infants · Macrocephaly · Magnetic resonance imaging · Subdural hemorrhage

Introduction

Macrocephaly or a rapidly increasing head circumference is a common indication for imaging in infants and young children. In the absence of a structural or significant developmental abnormality, these children are frequently diagnosed with benign enlargement of the subarachnoid spaces (BESS) [1–4]. At birth, these infants often have a large normal head size [5]. The head circumference rapidly increases during the first few months of age, with gradual tapering of head growth, typically normalizing by 2–3 years of age [6, 7]. BESS is more common in boys [2, 6], can be familial [6, 8], and does not require surgical intervention because it is self-limited and resolves without long-term sequelae [8–11].

There are no exact imaging criteria for diagnosing BESS, and the depth of the normal subarachnoid space in infants and young children is variable but often enlarged in relation to older children beyond 2 years of age [12, 13]. However, the expanded subarachnoid space in BESS is often described as greater than 4 mm in thickness from the frontal lobe cortical surface to the skull [14]. It is typically bifrontal in distribution with a widened interhemispheric fissure and prominent cerebral sulci, and there might be normal to mild ventriculomegaly [9, 14]. In the early CT era, differentiation of enlarged subarachnoid spaces from low-attenuation subdural collections was difficult [9, 11, 15–17]. However, this determination is more readily made on current imaging, especially US and MRI [18–20]. In the normal or expanded subarachnoid space, bridging and superficial veins course through the cerebrospinal fluid without displacement, and the arachnoid membrane is not visible. With a subdural collection or subdural hemorrhage (SDH), a separate compartment with displacement of the arachnoid membrane and central displacement of superficial veins toward the surface of the brain is evident, often with subtle flattening of the adjacent sulci [19, 21, 22] (Fig. 1).

BESS is a diagnosis that represents enlargement of the subarachnoid space, a normal space containing cerebrospinal fluid (CSF). It does not represent a separate fluid collection. A subdural hemorrhage or subdural collection is not an imaging feature of BESS. However, does the presence of an expanded or enlarged subarachnoid space potentially increase the likelihood of a child developing a spontaneous subdural collection or hematoma, even with little or no trauma? This question has been posed by some investigators [21, 23–26] because in the infant and young child presenting with an unexplained subdural hematoma or subdural collection, abusive head trauma must often be considered [27–32] (Fig. 2).

Subdural hemorrhage is a frequent finding in abusive head trauma (AHT), and in infants and young children subdural hemorrhage occurs much more commonly as a result of abusive rather than accidental head injury [27, 30, 32–34]. A differential diagnosis does exist, however, including accidental trauma, perinatal [35–37] and post-procedural subdural

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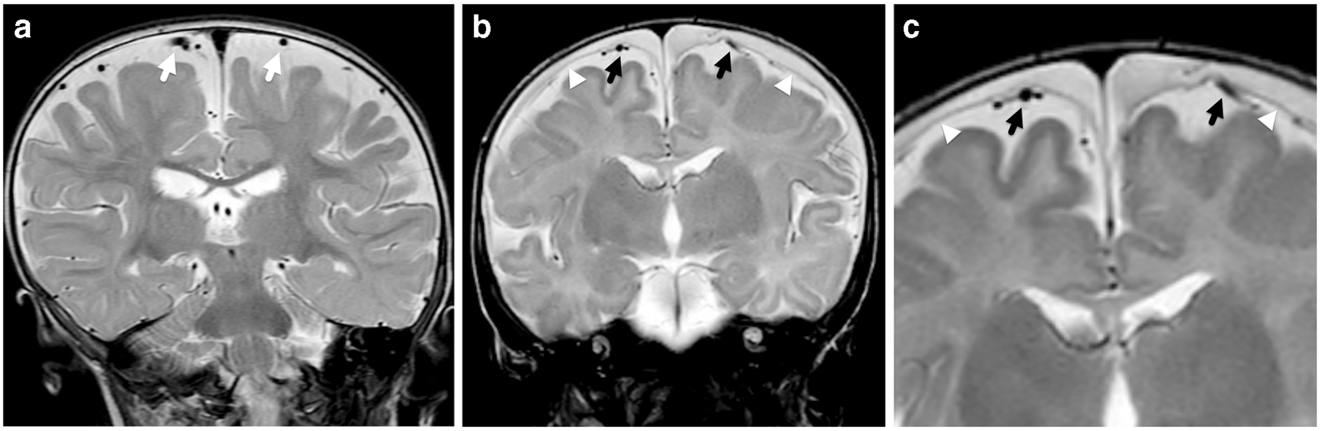

Fig. 1 Imaging of the subarachnoid versus subdural space in two infants. **a** Coronal T2-weighted MR image in a 1-year-old girl with macrocephaly and benign enlargement of the subarachnoid spaces demonstrates normal superficial and bridging veins (*arrows*) coursing through the mildly enlarged subarachnoid spaces. **b, c** Coronal T2-weighted MR images in a 3-month-old boy presenting with facial bruising show displacement of the superficial and bridging veins (*arrows*) by bilateral, proteinaceous subdural collections. The arachnoid membrane (*arrowheads*) is visible and displaced toward the brain

collections, and those presenting in the setting of certain metabolic disorders [38]. There is variability in the appearance of subdural collections — either hemorrhagic, mixed or more CSF-like — and there is variability in how subdural collections might be named [39, 40], potentially causing confusion, both clinically and in the literature.

Macrocephaly, enlarged subarachnoid spaces and subdural hemorrhage

Several case reports and small series in the literature suggest that subdural hemorrhage can occur spontaneously in infants and young children with enlarged subarachnoid spaces [21, 24, 41–46]. However, some reports were made prior to more modern imaging techniques and were limited in their methodology for evaluating and excluding abusive head trauma. Three recent publications, however, have addressed the prevalence of subdural collections/hemorrhage in the setting of enlarged subarachnoid spaces in infants and young children presenting with unexplained macrocephaly, and each addresses the diagnostic workup and concerns for AHT in these children.

McKeag et al. [4] in 2013 identified 4 cases of SDH among 177 children (2.3%) younger than 2 years with macrocephaly or an enlarging head circumference and enlarged subarachnoid spaces on CT or MRI. All four children were formally evaluated by the child protection team, and one of the four was found to have other concerning skeletal injuries supporting a diagnosis of abuse. However, in the other three, evidence of abuse was insufficient, and they were not reported to a state agency.

Later in 2013, Greiner et al. [2] identified subdural collections in 6 of 108 children (5.6%) with enlarged subarachnoid spaces among 168 children younger than 24 months referred for CT or MR imaging for macrocephaly or macrocrania. In four, the

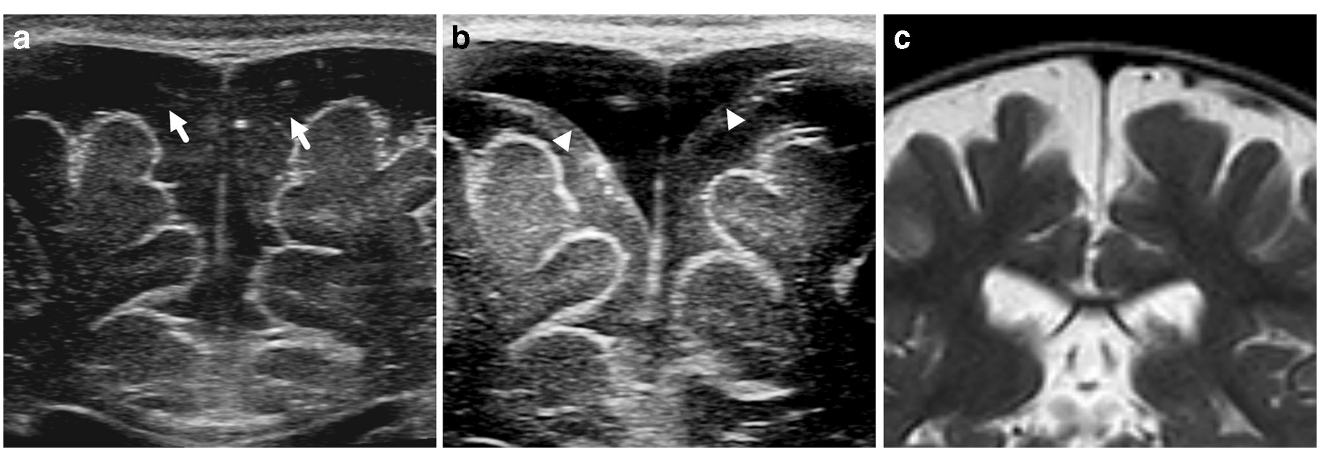

Fig. 2 Macrocephaly in a boy presenting at 4 months old. **a** Initial coronal US image at 4 months old shows enlarged subarachnoid spaces (*arrows*). **b** Follow-up coronal US at 5 months demonstrates bilateral anechoic subdural collections with displacement and visualization of the arachnoid membrane (*arrowheads*). A skeletal survey and abuse evaluation at this time were all normal. **c** Limited MR image at 10 months shows resolution of the subdural collections

subdural collections were small, unilateral and homogeneous on MR. In the remaining two cases, the subdural collections were larger, bilateral and more complex, with heterogeneous signal characteristics and membranes; one had CT and MR characteristics suggesting recent hemorrhage. These two children underwent a formal child abuse consultation and were subsequently reported to children's services. Each of these two children had a normal initial and follow-up skeletal survey, and on a dedicated retinal exam, one had retinal hemorrhages concerning for abuse. Two others with subdural collections had dedicated retinal exams for unrelated reasons and each exam was normal. Importantly, no subdural hemorrhages or subdural collections were found in the 60 children having normal subarachnoid spaces on imaging.

More recently, Tucker et al. [3] identified 21 subdural collections among 538 (3.9%) US, CT and MRI studies performed for unexplained macrocephaly in children ≤2 years of age. Eighteen subdural collections were identified among 311 cases (5.8%) with enlarged subarachnoid spaces, or BESS, and the authors found a strong association between greater degrees or depths of enlargement of the subarachnoid spaces and the prevalence of subdural collections. Three of 10 children with subdural collections identified prospectively underwent a formal abuse consultation, with one subsequently reported [3]. This child had a normal follow-up skeletal survey and a normal retinal exam but large bilateral subdural hemorrhages resulting in the child's macrocephaly. Follow-up imaging was performed in 7 of these 10 children over a period of 3–24 months, with nonsurgical resolution of their subdural collections [3].

Each of these authors was evaluating a population of young children referred for macrocephaly and seeking to find a prevalence of potentially non-traumatic subdural collections in those with enlarged subarachnoid spaces. Although each study found a small percentage of patients with enlarged subarachnoid spaces and a coexistent subdural hemorrhage or subdural collection without an identified traumatic cause, each publication also found one or more cases of children with macrocrania and a subdural collection/SDH that had other injuries concerning for abuse. Furthermore, not every child with a subdural collection was evaluated for potential abuse, so unfortunately the prevalence of abuse in these cases remains unknown.

With this question in mind, Hansen et al. [47] performed a retrospective review of 149 cases of SDH in children <2 years of age. The authors studied 43 children with SDH and mild or no symptoms to determine the prevalence of other concomitant suspicious injuries and compared this to the number of concomitant suspicious injuries in those presenting with SDH and severe symptoms (106 patients). However, this was a select population because the cohort included only children with an SDH on CT or MRI and also an evaluation by their child protection team. This might have excluded children presenting with small subdural collections and no child protection team referral. In their cohort, those presenting with severe clinical symptoms were 5 times more likely to have a concomitant suspicious injury [47]. However, just over 60% of children in the mild clinical group were also found to have at least one other concomitant suspicious injury, and this included 6/17 patients (35%) with BESS. Overall, although the 34 BESS patients had fewer concomitant suspicious injuries, 17/34 children (50%) with BESS had another suspicious injury [47]. Despite the select population, this study underscores that an asymptomatic or mildly symptomatic subdural collection or subdural hemorrhage in the presence of BESS should not automatically be attributed only to the expanded subarachnoid spaces, but might be the result of an abusive injury.

Large subdural collections causing macrocephaly

Young children presenting with macrocephaly might also be found to have moderate to large subdural collections, but with the subdural collections causing their macrocephaly as opposed to enlarged subarachnoid spaces [3, 48] (Fig. 3). In these cases, abusive head injury must be considered because these subdural collections are frequently presumed to be chronic subdural hemorrhages or subdural hygromas occurring as a result of prior trauma [40]. It must be kept in mind that the imaging appearance of subdural collections can be complex and that correlation with timing of a prior injury might not be possible on the imaging characteristics alone [39, 40, 48–51]. Low-attenuation subdural collections can occur from other etiologies [38] and can occur acutely [39, 40, 44, 49, 51, 52], thus not representing a chronic SDH but rather an abruptly developing subdural hygroma or fluid collection containing CSF or interstitial fluid leakage [40] mixed with blood. In 1998, Dias et al. [51] described the development of new bilateral low-attenuation subdural collections that were not present on an initial head CT obtained only 17 h prior in a 1-month-old abused infant. These were described as similar in appearance to chronic subdural hemorrhage, but they developed rapidly. In 2004, Zouros et al. [49] examined five infants with presumed AHT presenting with bilateral low- or mixed-attenuation subdural fluid collections, four described as having split cranial sutures or a large head circumference. In each case, a communication of the subarachnoid with the subdural space was shown, confirming that low- or mixed-attenuation subdural collections can occur rapidly and represent cerebrospinal fluid mixing with subdural blood following presumed traumatic separation of the dural and arachnoid interface [49].

Feldman et al. [48] studied 383 children with SDH on CT (64% with MRI) from a larger cohort of 459 children with AHT. Those evaluated were classified as having acute SDH (*n*=291) or acute/chronic SDH (*n*=92). The investigators found a similar percentage of children in both groups presenting with acute neurologic compromise or symptoms, as well as retinal hemorrhages and extracranial injuries, suggesting that both groups were likely suffering from a new abusive injury, despite the imaging appearance of the SDH [48]. Within their

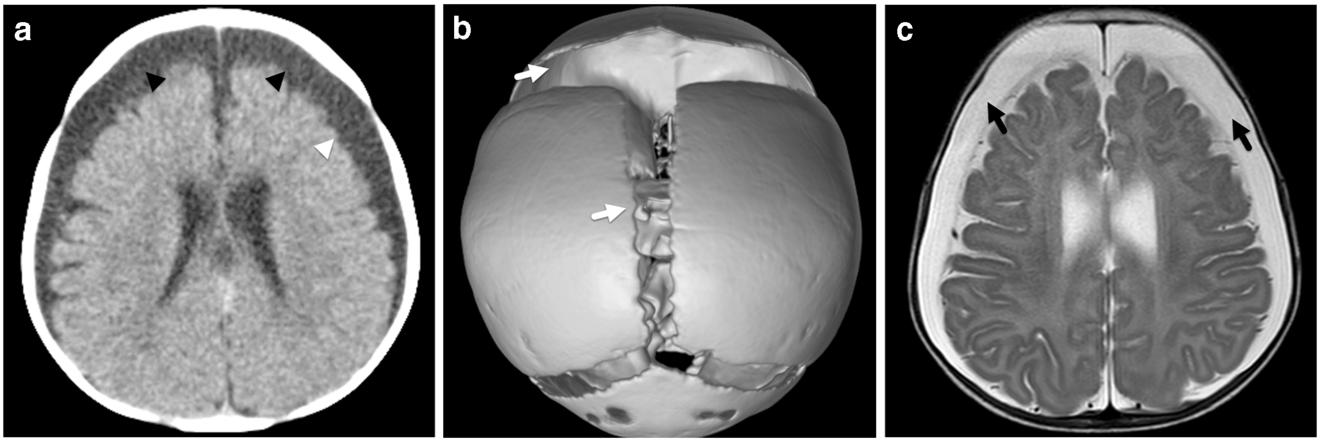

Fig. 3 Increasing head circumference, vomiting and weight loss in a 4-month-old girl who was abused. **a** Initial axial head CT image demonstrates bilateral low-attenuation subdural collections (*black arrowheads*) resulting in subtle flattening of the left frontal cerebral sulci (*white arrowhead*). **b** Three-dimensional reconstruction of the skull shows splaying of the cranial sutures (*arrows*). **c** Axial T2-weighted image from an MRI obtained the next day more easily shows large bilateral subdural collections (*arrows*). Notice the absence of veins coursing through the subdural collections

study cohort, a small subset of children presented with asymptomatic macrocephaly. More children described as having acute/chronic SDH (7.5%) presented with asymptomatic macrocephaly than those with only acute SDH (1%) [48]. Unlike other recent studies [2, 4], however, the macrocephaly was caused by the subdural collections as opposed to enlarged subarachnoid spaces. Importantly, none of the subset of patients presenting with asymptomatic macrocephaly died, and on imaging their acute SDH was contained solely within areas of low-attenuation or chronic SDH, more typical of the scenario in children with episodes of spontaneous rebleeding [50].

More recently, Wright et al. [50], in evaluating the frequency of rebleeding on follow-up imaging in 160 children with SDH from AHT, found an association between those that rebled and macrocephaly at both initial presentation and follow-up. However, many children also rebled with a stable or decreasing head circumference because they had enlarging extra-axial spaces and subdural collections from progressive brain volume loss as a result of the prior AHT [50]. The larger the subdural collections were, the more likely they were to rebleed; the maximum depth of the SDH was the factor most strongly associated with rebleeding [50]. The presence of ventriculomegaly was also associated with rebleeding. Importantly, all episodes of rebleeding occurred without new neurologic symptoms, and rebleeding always occurred in preexisting subdural collections [50].

Etiology of subdural hemorrhage/collections with enlarged subarachnoid spaces

Although enlarged subarachnoid spaces are present in the setting of BESS, prior trauma, including AHT, can also result in enlarged extra-axial spaces from both parenchymal volume loss and post-traumatic communicating hydrocephalus [53]. This can complicate the interpretation of imaging findings in a relatively asymptomatic child with presumed BESS and a small subdural collection because it can be difficult to determine the causal relationship between these two entities.

In a child presenting with a potentially spontaneous SDH or subdural collection in the setting of enlarged extra-axial spaces and little to no known trauma, the etiology of the subdural collection remains uncertain, although several etiologies have been proposed. Stretching or tearing of bridging veins from the unusually enlarged extra-axial spaces has been suggested by multiple authors [21, 24, 46, 54–56]. Papasian and Frim [23] proposed a mathematical model of this hypothesis and suggested that with a thickness of the subarachnoid space beyond 6 mm, even minor trauma might potentially stretch the veins beyond a typical breaking point, resulting in subdural bleeding. However, others have suggested that the enlarged spaces actually have a protective or dampening effect, thus, potentially decreasing the risk for subdural development [57]. A disruption of the arachnoid–dural interface has been suggested [44, 58]. Zouros et al. [49] demonstrated a free communication with rapid accumulation of injected radiotracer passing from the subarachnoid to the subdural space in five infants with suspected AHT. This mechanism would then permit the development of subdural collections either similar or nearly similar to CSF in appearance. This arachnoid–dural disruption could alter the arachnoid granulations or the normal CSF absorption, leading to subsequent expansion of the subarachnoid space to occur following trauma. Therefore, the expanded subarachnoid space might not always predate the development of the observed subdural collection or SDH [49], but rather expand as a consequence of prior hemorrhage or trauma. An intradural venous plexus, potentially contributing to CSF absorption in the infant, has also been proposed as a mechanism by which thin, CSF-like collections can occur in the subdural space [59, 60]. Last, recurrent bleeding from subdural membranes in preexisting chronic subdural hemorrhages is known to occur [61].

BESS is common [1, 2] and, infrequently, small, presumably spontaneous subdural collections might be found in this population of infants and young children presenting with macrocephaly and enlarged spaces [2–4] (Fig. 4). So, where do we go from here to detect — but not potentially overdiagnose — abusive head trauma in this population? Vinchon et al. [44], in 2010, while evaluating 16 infants presenting with presumed spontaneous SDH in infancy, reminded us that the absence of other stigmata of trauma does not necessarily exclude trauma as an etiology. Although enlarged subarachnoid spaces in infants rarely contribute to the development of small subdural collections, the vast majority of SDH encountered in this population is post-traumatic and usually occurs as a result of AHT [62]. Importantly, even in the cases presenting with asymptomatic subdural collections or hemorrhage in recent studies evaluating infants with macrocephaly, up to 35% [2–4, 47] of the cases with subdural collections were also found to have other concerning features suggesting abuse. In the cases where other concerning findings were present, such as extracranial injuries or retinal hemorrhages, the subdural collections were thought to be abusive in etiology and not spontaneous.

Imaging and reporting approach

In my practice and at my institution, we have come to recognize that small subdural collections might infrequently complicate cases that would otherwise be diagnosed with BESS. Although there is variability in how each radiologist practices, some factors guide my decision-making in how to generate my radiology report in these cases. As with recent studies [2, 3], the degree of expansion of the subarachnoid space is a consideration because I would not typically expect a spontaneous subdural collection to be present in a child with normal subarachnoid spaces [2], but to more likely occur in a child with very expanded extra-axial spaces [3]. The contents of the subdural collections, as well as the size, are also considerations. Larger, clearly hemorrhagic subdural collections are not typically as issue for most radiologists because these are predominantly post-traumatic and should raise concerns for AHT. However, trace or very thin subdural collections, even with subtle proteinaceous contents, are presumed to be less alarming than those that contain more clearly hemorrhagic components. However, I recognize that CSF-like collections can be seen acutely and hemorrhagic contents can evolve over time. Symptomatology is important, as well, because most of the recent literature focuses on these spontaneous subdural collections as being found in a population of infants and young children who are essentially asymptomatic, and not in those presenting with severe clinical symptoms or brain insult, which would be more indicative of AHT [2–4]. I remain old-school in that I, not infrequently, call the referring physicians in cases where I encounter these small subdural collections to discuss any concerns; I also remember how important it is to "always look in the jacket" and review any prior imaging that is available that might help guide my decision-making. I recognize that this approach is not universal, but it presents my current practice pattern. In contrast, some authors [47, 63] advocate for screening all infants and young children presenting with small subdural hemorrhages and subdural collections, and future studies might help to determine the actual prevalence of abuse in this population and whether these thin, asymptomatic subdural collections ever evolve into large, devastating subdural hemorrhages.

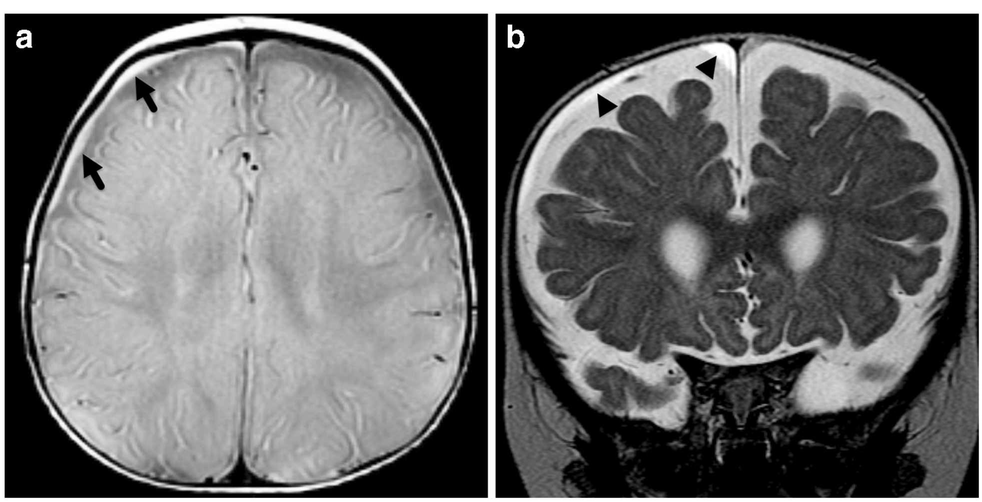

Fig. 4 Macrocephaly in a 9-month-old boy. **a** Axial first echo T2-weighted MR image shows a thin, proteinaceous subdural collection (*arrows*). **b** Coronal T2-weighted MR image shows the thin subdural collection (*arrowheads*) in the setting of mildly enlarged subarachnoid spaces

Conclusion

Recent studies do support that enlarged subarachnoid spaces can predispose infants and young children to the rare development of a subdural collection without prior recognized trauma. However, the role of screening each of these children for the etiology of the subdural collection and any additional injuries remains undefined. Going forward, a description as to the contents and size of the subdural collection or SDH is important, as is symptomatology of the child. Trace, essentially asymptomatic subdural fluid, similar to CSF in appearance, in the setting of expanded subarachnoid spaces might not be as concerning for prior trauma as larger or clearly hemorrhagic subdural collections. However, any unsuspected SDH or subdural collection in an infant or young child deserves thoughtful consideration for potential etiologies, including abusive head trauma, because even infants and young children with enlarged subarachnoid spaces might have suffered prior abuse.

Compliance with ethical standards

Conflicts of interest None

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