5. Subdural Hematoma in Children

Guy N. Rutty and M.V. Waney Squier

Introduction

There are few areas within medicolegal practice at present that generate as much controversy as the interpretation of findings upon which mechanisms of injury to children, living and deceased, are based. High-profile cases within the English legal system highlight the difficulty of diagnosing the cause of pathologic findings "beyond reasonable doubt." The pathologist may be faced with a panel of experts clinging to "mainstream thinking" backed by anecdotal and personal experience rather than considering peer-reviewed research and literature. This is one area where evidence-based medicine is an absolute requirement, particularly when evidence is being put before a court.

In recent times the question of who should be undertaking these examinations has been raised. Should it be a forensic pathologist who may have little, if any, formal pediatric training, or a pediatric pathologist who equally may have little, if any, forensic training? The solution seems obvious: have both pathologists present at the autopsy, especially when the pathologic findings may have both a natural and/or an unnatural causation. Ultimately, the pathologist's duty is to the court, as an unbiased witness to present and interpret the findings within his or her limits of expertise.

This chapter addresses a single pathology from an area of contentious medicolegal practice, that is, the subdural hematoma (SDH), which is regarded by some as highly indicative of nonaccidental injury. Whereas most SDH in infants is caused by trauma, many other natural and unnatural causes have been described. We review all causes that could be identified from the world literature as possible causes of SDH and consider the ages when they occur, the associated medical or pathologic findings, and the hypothesized mechanisms of causation. Only by considering all of the causes examined within this chapter can we start to plan the investigations required to determine the causation of SDH in childhood.

Incidence

Subdural hemorrhage occurs in 10.9 per 100,000 infants aged 0 to 2 years, 20.8 per 100,000 infants younger than 1 year.[1] Most SDH occurs in infants aged 0 to 4 months.[2] The age distribution is similar for all causes of traumatic SDH, indicating that pathogenesis is dependent on age and independent of cause.[3]

Nature and Distribution of Subdural Hematoma

Subdural hemorrhage results from bleeding into the potential space just beneath the free edge of the dura. A layer of cells the *dural border cells* form a loosely adherent junction with the arachnoid membrane, and it is into this layer that subdural bleeding occurs.[4] The cells are clearly very loosely adherent, if not a genuine space in life, as the dura is very readily lifted from the arachnoid at autopsy without evident attachment. Further, SDH usually is very extensive[5] and, particularly in infants, frequently forms a widespread thin film over the cerebral hemispheres. Subdural hematomas may connect between all subdural compartments, and bilateral subdural hematoma can be drained with a shunt placed on only one side of the head.[6,7] In older children SDH is more likely to form a thick, space-occupying unilateral hematoma, similar to the pattern in adults following trauma.

Natural History

In the natural history of subdural hematoma, it resolves by formation of a granulating membrane.[5,8,9] In the first days after bleeding, macrophages enter the clot, and release of enzymes causes clot lysis. Hemoglobin is converted to hemosiderin which stains blue with Perls reaction. This process is thought to take 48 hours from the time of bleeding. However, neither this nor other histologic reactive processes can be precisely timed, especially if the infant has been nursed on a ventilator for the last hours or days of life when reactive processes are altered by impaired or absent cerebral blood flow (respirator brain).

After 3 days the infiltrating macrophages take up red cells and contain brown breakdown products within their cytoplasm. Fibroblasts and capillaries grow into the clot in the first 3 days and form many large vascular channels that are particularly numerous in two bands, at the junction of the healing clot with the free edge of the dura and at the free deep border of the membrane. Although the healing adult subdural membrane is described as granulation tissue, Friede[9] has suggested that in infants the reactive membrane can be distinguished by the very large size and number of in-growing thin-walled sinusoidal capillary vessels that he termed *macrocapillaries*. By 10 days the membrane becomes visible to the naked eye. It may be extensive and thin, often no thicker than the dura, and certainly beyond the resolution of routine computed tomography and magnetic resonance imaging (MRI) brain scans. In time the numbers of capillaries are reduced, and the membrane becomes predominantly fibrotic, with calcification or even areas of ossification. In very chronic cases there may be proliferation of arachnoid cells in the arachnoid villi resulting in impaired drainage of cerebrospinal fluid (CSF).[10]

Chronic Subdural Hematoma

There are two forms of chronic SDH. In a few cases the original blood clot becomes liquid and is encapsulated by a fibrous membrane. The resulting "subdural hygroma" has a similar shape and location to the original hematoma.

In most cases there is more widespread accumulation of fluid in the subdural space. Transition of acute infantile subdural hematoma into chronic SDH has been

recognized for many years.[11] This is a delayed process. In the series reported by Hwang and Kim,[12] 3 of 16 acute SDH in infants younger than 1 year old became chronic, after intervals of 68, 90, and 111 days after initial trauma. The development of chronic SDH may be recognized by clinical signs of enlarging head or raised intracranial pressure or by the scan appearance of fluid collections in the subdural space. Subdural hemorrhages may present clinically with rebleed after minor trauma or even spontaneously.[13]

There are four pathologic mechanisms for development of chronic SDH:

1. The most important is repeated hemorrhage into the granulating membrane of healing acute SDH.[14,15]
2. Leakage of CSF through an opening in the subarachnoid allows CSF to enter the subdural space. This can occur after shunt placement in hydrocephalic babies. The CSF mixes with blood and results in a thin xanthochromic subdural fluid collection.[7]
3. Babies with brain atrophy may be more susceptible to development of chronic SDH as are result of tension on the dural border layer as the arachnoid collapses with the shrinking brain.[4]
4. After an infection or inflammatory process; subdural empyemas can result from sinusitis or otitis media.[16,17]

The pathogenesis and mechanisms of development of chronic subdural fluid collections are far from well understood. Although rebleeding into subdural membranes is very well recognized by pathologists,[9,11] the relationship between subdural and subarachnoid spaces is complex. Vinchon et al.[18] performed serial imaging in infants with accidental traumatic SDH. They noted that initial bleeding into the subarachnoid space preceded subdural fluid collections. They proposed that this process resulted from impaired CSF absorption at the arachnoid villi, and in one case they noted an extending tear in the arachnoid membrane. The pathophysiology of CSF accumulation in infantile SDH appears to be age specific. Hwang and Kim[12] described the evolution of acute to chronic SDH in three cases. In these cases, small acute subdural hematomas disappeared, followed by widening of the subarachnoid space and then by accumulation of subdural fluid at a much later date (68, 111, and 90 days). An MRI study of nine birth-related subdural hemorrhages failed to demonstrate persistent SDH at 4 weeks of age.[19] The experience of Hwang and Kim[12] suggests that early radiologic improvement does not exclude later development of chronic SDH in infancy. A further point of note is that imaging studies only recognize fluid accumulation; a thin granulating membrane would not be identified by routine scans without contrast enhancement.

Nontraumatic Causes of Subdural Hematoma in Children

Fetal

The most common form of antenatal intracranial hemorrhage is SDH that can be diagnosed by ultrasound or MRI.[20] Fetal SDH carries significant morbidity and mortality and is associated with arteriovenous malformations, tumors, disorders of coagulation, drugs (aspirin and warfarin), cholestasis of pregnancy, fetal distress, and hypoxic events, or it may be considered idiopathic.[21,22] Trauma as a cause has

been reported from traditional massage techniques to encourage cephalic version of breech presentations or from true maternal injury such as assault (so-called "battered fetus"), falls, and motor vehicle incidents[23].

Neonates

The incidence of birth injuries is estimated at 2 to 7 cases per 1000 live births.[24] They include soft tissue and skeletal injuries as well as subdural and retinal hemorrhages, all of which can be misinterpreted as nonaccidental injuries. Subdural hemorrhage is reported in one series as the most common form of intracranial birth related pathology, accounting for 73% these findings.[25] Many SDHs are clinically silent, small, and completely resolve within 4 weeks of the delivery.[19]

An MRI study of asymptomatic neonates has shown a 9% incidence of SDH.[19] Other studies have shown SDH in up to 50% of normal deliveries.[26,27]

Mode of Delivery

A number of maternal and fetal factors have been implicated as the cause of SDH related to the birth of the infant. These factors include cephalopelvic disproportion, prematurity, both maternal primiparity and grand multiparity, and both precipitous and prolonged labor.[28,29] The mode of delivery of the infant also must be considered, as this factor affects if and where the SDH may occur. However, there does not appear to be a higher incident of occurrence of SDH whether forceps or vacuum was used to assist the delivery.[30] Having said this, in the case of forceps delivery, the angle of rotation may be of importance. Hankins et al.[31] studied forceps rotation and found that a single case of SDH occurred with rotation greater than 90 degrees.

Tentorial and interhemispheric SDH have been described with normal vaginal delivery.[28] It is hypothesized that occipitofrontal compressive forces stretch the internal cerebral veins, the basal veins of Rosenthal, and the mobile aspect of the vein of Galen, resulting in tearing injuries either to the veins themselves or to the falx or tentorium.[28] Subtentorial posterior fossa SDHs have been reported in unassisted vaginal deliveries but more frequently in forceps and vacuum assisted deliveries.[32,33] Although osteodiastasis associated with forceps delivery has been considered the cause of posterior fossa SDH, others have rejected this theory. An illustrated theory to support tearing injury of the deep veins as the cause of SDH during vacuum extraction has been put forward by Hanigan et al.[34] The operative procedure of cesarean section itself is not reported as a cause of SDH.

When considering the location of birth-related SDH, Whitby et al.[19] found only one SDH in the supratentorial compartment alone, 6 of 9 were in the posterior fossa, and 2 of 9 were in both supratentorial and infratentorial compartments. These findings correspond with other reports in which no isolated supratentorial hemorrhages were identified. This does not support the contention that these subdural bleeds result from tearing of the draining veins that insert over the frontal vertex but suggests that these bleeds are the result of tentorial tearing or bleeding from the dural folds, which are prominent in the posterior fossa. Bleeding from dural folds is more frequent than from less vascular dura over the convexities.

Perinatal Hypoxia

Perinatal hypoxia has been considered a risk factor for SDH during birth. However, in a paper on risk factors for intracranial hemorrhage in full-term infants, Jhawar

et al.[35] draw attention to the earlier publication of Wigglesworth and highlight that this relationship should be considered with caution because the hemorrhage may be secondary to birth trauma, which in turn may precipitate a respiratory crisis and hence the hypoxic event, rather than vice versa, that is, the hypoxic event having been caused by the SDH. Coexisting cerebral trauma as the cause of SDH is also proposed and supported by Chamnanvanakij et al.[27]

Cerebral Infarction

Subdural hemorrhage is described in association with cerebral infarction in the neonate.[36,37] The mechanism is unknown. It has been suggested that the blood leaks from the infarcted brain tissue into the overlying meninges.[38] An alternative hypothesis is that subdural hemorrhage resulting from some other cause, such as torn blood vessels, displaces the brain and compresses the arterial supply, leading to infarction.[37]

Total Parenteral Nutrition

Intracranial complications of total parental nutrition (TPN) are rare and the underlying mechanisms unclear. Although subdural collections, whether they consist of transudates or fat effusions, are reported in the literature, subdural hematomas or blood-stained collections are not.[39] Tuthill et al.[39] draw attention to the hypothesis that retrograde venous flow occurring in response to raised pulmonary vascular resistance results in rupture of the bridging veins. The TPN fluid, which has been infused into the superior vena cava, then can enter the subdural space via the injured intracranial vessels. Retrograde flow is also postulated to occur as a result of high pulmonary pressures and reduced venous return caused by mechanically assisted ventilation.

Neuroendocrine Syndromes

Prader-Willi syndrome is a neuroendocrine disorder with chromosomal abnormalities (characterized by deletion of the proximal part of the long arm of chromosome 15 among other abnormalities) first described by Prader, Labhart, and Willi in 1956.[40] The diagnostic features are those of obesity, short stature, and developmental delay, with the child presenting with profound muscular hypotonia, swallowing difficulties, and hypogonadism. A single case has been reported of a 10-day-old neonate with bilateral SDH of the posterior falx with associated extradural hemorrhage, which was hypothesized to be caused by a genetically related abnormality of homeostasis, although the specific homeostatic abnormality was not stated.[41] The infant had been delivered by cesarean section following breech presentation, although these delivery related mechanisms were excluded as the cause of the SDH.

Other Causes

Other causes of neonatal SDH include thrombocytopenia, vitamin K deficiency, hemophilia, hepatic disease, infection, and disseminated intravascular coagulation (DIC). Maternal use of aspirin may result in SDH because of placental crossing of the drug.[42]

Infants

Coagulation and Hematologic Disorders

By far the largest literature on natural causes of SDH in children relates to hematologic and coagulation disorders. These disorders can affect the fetus, newborn, infant, and juvenile but are all considered in this section. Because of the shear number of papers, particularly in relation to hemophilia, only selected references are given to relevant conditions.

Severe hemophilia A (factor VIII deficiency) can present with intracranial hemorrhage in neonates. This condition can result from congenital hemophilia or transplacental transfer of acquired factor VIII:C inhibitor from maternal circulating immunoglobulin G class antibodies[43]. Despite the pressures involved in vaginal delivery, intracranial hemorrhage of all types is estimated to occur in only 1.0% to 4.0% of infants with hemophilia A. It is associated with traumatic and instrument-assisted deliveries but also has been reported to be spontaneous in nature, occurring several days after birth[44]. There is no specific distribution for the SDH, although in several reported series the bleeds were all supratentorial and unilateral in location.[45,46] The mortality from SDH has dropped in modern times to approximately 30%.[47]

Hemophilia B (factor IX deficiency) also may present with SDH in the neonatal period.[48] As with hemophilia A, the most common site for infant bleeds is intracranial, with SDH the most common type.[49] The mean age for intracranial bleeds in hemophilia B is younger than that for hemophilia A: 4 to 6 years as opposed to 10 to 10.5 years.[50]

Hemophilia, afibrinogenemia, leukemia, and thrombocytopenia (various types) have all been reported to cause SDH in school-age children. Although minor trauma has been put forward as a common cause, SDH may be spontaneous in nature.[51,52]

Four-factor deficiency is a very rare, autosomal recessive, inherited bleeding disorder involving the vitamin K-dependent coagulation factors. A single case of a 3-month-old male child with the deficiency who presented with a right-sided SDH has been reported.[53]

Another rare factor deficiency is factor V deficiency. A single case report of a male with postdelivery SDH and three more SDHs in the first 10 months of life was reported by Salooja et al.[54] Factor V deficiency is also associated with other congenital anomalies, including cardiac failure, transient hypertension, and renal tract and intracranial anomalies.

Congenital deficiency of factor VII, an autosomal transmitted disorder, usually is asymptomatic. Although it has been reported to be associated with arterial and venous thrombosis, only a single case of a homozygotic male infant 7 months old presenting with a left occipitoparietal SDH has been reported.[55] The child presented after an episode of minor head trauma.

Factor XIII deficiency is an autosomal recessive disorder in which bleeding occurs in less than 1% of affected individuals. A single case of a 38-month-old male child with factor XIII deficiency who had a left-sided SDH was reported by Larsen et al.[56]

Hermansky-Pudlak syndrome (HPS) is an autosomal recessive inherited disorder characterized by oculocutaneous albinism, tissue accumulation of choroid pigment, and bleeding diathesis as a result of platelet disorder. A single case of a 7-week-old male child with HPS who presented with a left-sided occipital SDH has been reported.[57]

Disorder of the function of fibrinogen, as highlighted earlier, may result in SDH. Autosomal dominant congenital dysfibrinogenemia has been recorded in several hundred families. Although they may be clinically silent, severe forms may present with bleeding, thrombosis, or abnormal wound healing. Occasional case reports, such as the 2-year-old male child reported by Al-Fawaz and Gader,[58] illustrate the complication of this disorder with SDH.

Fatal intracranial hemorrhage in sickle cell disease, although rare, is more common in children than in adults. The site of the bleed may be subdural.[59] The mechanism behind the SDH of sickle cell disease remains unproved, although it has been speculated to result from vascular abnormalities. In sickle cell patients, venous capillary saccular dilatations and ectasias, which are known to occur, may rupture and result in SDH.

Infections

A number of reports of the association of cerebral or systemic bacterial, viral, and parasitic diseases that can affect children and be complicated by SDH appear within the literature, but care must be taken to differentiate those diseases that cause effusions rather than hematomas.

Congenital toxoplasmosis can result in neonatal central nervous system damage. Subdural hematoma has been reported in association with this infection. Toxoplasmosis has been postulated to cause toxic damage to the dural blood vessels, resulting in increased permeability and rupture and thus formation of SDH.[60]

Malaria is another parasitic disease that can be listed as a cause of SDH. However, malaria has been reported to result in subdural effusions in children aged 11 to 66 months rather than hematomas.[61]

Bacterial meningitis has been reported to result in both subdural effusions and hematomas.

A Polish-language publication reported seven cases from a series of 97 children with toxic diarrhea who had associated SDH.[62] The SDH was reported in those cases with central nervous system signs and symptoms. None of the cases were reported to have hypernatremia or dehydration, although vascular manifestations and vitamin K abnormalities were reported.[62]

Although there is a single case report in Japanese of herpes simplex encephalitis (HSE) associated with SDH, Kurtz and Anslow[63] in their series of 13 infants with HSE draw attention to the fact that none of their cases had SDH. In fact, they use the presence of SDH to differentiate HSE from nonaccidental head injury.[63]

Finally, a single case of SDH following chronic otitis media is reported in the literature.[64]

Hemorrhagic Shock and Encephalopathy Syndrome

Hemorrhagic shock and encephalopathy syndrome (HSES) was first reported by Levin et al.[65] in 1983. This acute, frequently lethal syndrome usually occurs at about 3 to 4 months of age.[66] The cause remains unknown.[67] There is a prodromal period lasting on average 2 to 3 days during which the child exhibits fever, irritability, diarrhea, or signs of an upper respiratory tract infection. It then deteriorates into profound shock, seizures, coma, DIC, and oliguria. Cerebral edema, hypoxia, and boundary zone infarction may be seen. Rarely, SDH and retinal hemorrhages are seen in these cases and are attributed to the coagulation disorders present. The

authors have seen one case mimicking nonaccidental injury that ultimately was clinically diagnosed as consistent with HSES.

Hydrocephalus and Benign Extraaxial Collections

Hydrocephalus can be classified as internal, external, or communicating, depending on whether the abnormal CSF accumulation is within the ventricles, over the surface of the brain, or both.

Hydrocephalus is well recognized following SDH, and this complication represents the primary indication for surgical drainage of SDH.[68] The blood collections impede drainage of CSF via the arachnoid villi, leading to CSF accumulation.

Benign extraaxial collections of infancy are a complex and incompletely understood group. This is a self-limiting disorder, sometimes with a family history of dominant inheritance. Affected children present under 1 year of age with macrocrania (defined as an occipital frontal circumference at or greater than the 98th percentile) or rapid head growth and can show vomiting, irritability, seizures, and failure to thrive. Psychomotor development usually is normal.[69] Original reports considered the fluid collections to be located in the subdural space.[70] However, modern neuroimaging suggests that in many cases the fluid is within the subarachnoid space.[71] There seems to be no consistency, and the term *benign extraaxial collections* encompasses fluid collections in either compartment. These collections may be either protein-rich effusions (protein content ≥40 mg/dl) or gross blood (red cell count >1,000,000/ml^3). The cause of the collections is unknown, although typically there is no history of previous intracranial infection or trauma (see next paragraph). It has been hypothesized that the collection interferes with normal CSF absorption, leading to communicating hydrocephalus.[72]

Piatt[73] updated the controversial debate on benign extraaxial collections, considering them to be a form of external hydrocephalus. He suggests that that as many as 11% of infants with external hydrocephalus may develop SDH.[73,74] It is thought that the craniocerebral disproportion increases the distance that the bridging veins must traverse, rendering them vulnerable to shearing forces that make the infant susceptible to SDH either spontaneously or after otherwise "inconsequential" trauma. Papasian and Frim[75] developed a mathematical model that supported the hypothesis. Piatt describes a child with SDH and external hydrocephalus in association with retinal hemorrhages. He warns of the potential for making the mistaken diagnosis of child abuse in these cases, which is further discussed by Pittman.[76]

Space-Occupying Lesions

Subdural hemorrhage is a recognized complication of intracranial tumors in children. This section describes a number of intracranial space-occupying lesions associated with SDH.

Meningioma is infrequent in the first decade of life. A single case of chronic SDH has been reported in a 5-year-old male child with a frontal chordoid meningioma associated with bilateral SDH.[77]

A single case in Japanese reports a lesion described as a "neuroepithelial cyst" with associated SDH overlying the left temporal tip on histology in an 8-year-old male child.[78]

Two cases of SDH and intracranial sarcoma of childhood have been identified.[79,80] In each case, a separate mechanism for SDH is proposed. In the first, SDH is attrib-

uted to bleeding from tumor vessels within the subdural space. The second suggests that SDH is the primary pathology, possibly of traumatic origin, with the sarcoma developing several years later at the site of the previous SDH cavity. It is hypothesized that a chronic inflammatory reaction to SDH with proliferative membrane formation ultimately leads to the development of sarcoma. This parallels the occurrence of chronic pleural inflammation with the ultimate development of pleural malignancy. It is also hypothesized that surgical intervention or repeated intracranial taps amplify the risk.

A single case of an 8-month-old child with juvenile xanthogranuloma was reported by Labalette et al.[81] On presentation the infant had a chronic subdural hematoma attributed to spontaneous hemorrhage.

A 2-year-old male child with extramedullary hematopoiesis (EMH) of the cranial dura with associated SDH has been reported.[82] The EMH had formed a space-occupying lesion within the cranium and was attributed as the cause of the SDH.

Hypernatremia

Whether hypernatremia (defined as serum or vitreous sodium in excess of 150 mEq/L) is the cause or the result of a subdural hematoma has been discussed in the literature since the 1950s. Prior to Kempe's article on "The Battered Child Syndrome," it had been theorized that the dehydration associated with hypernatremia resulted in brain shrinkage, which in turn stretched the bridging veins, predisposing to rupture and SDH.[83,84] However, others have considered that it is the cause of the dehydration (e.g., severe intracranial disease, surgical procedures, or encephalopathy leading to central diabetes insipidus) and not the primary hypernatremia that results in SDH.[86] Handy et al.[85] review several series of cases where children died of nontraumatic deaths with evidence of hypernatremia, although SDH was not found at autopsy. In their own series, single cases were identified where hypernatremia and SDH coexisted; however, clinical documentation indicated that hypernatremia followed the onset of SDH. Finberg et al.[86] demonstrated that peritoneal administration of hypertonic sodium chloride solution to kittens could result in SDH, but the methodology and model have been criticized. One mechanism that could be considered from the observations of Finberg et al. in relation to infant accidental salt poisoning is that venous sinus thrombosis, a recognized complication of hypernatremia, is itself associated with subdural haemorrhage.[86] However, other papers reporting both accidental or intentional salt administration to children do not report the presence of SDH.[83,85]

Although the overwhelming evidence reported in the medical literature indicates isolated hypernatremia does not cause SDH, in extremely rare cases hypernatremia has been reported to be the cause of SDH.[87,88]

Connective Tissue Disease

Two connective tissue diseases have been reported to present with SDH in childhood: Ehlers-Danlos syndrome (EDS) and osteogenesis imperfecta (OI).

Ehlers-Danlos syndrome is a heterogeneous group of inheritable connective tissue disorders characterized by skin laxity, joint hypermobility, and tissue fragility. There are six types classified according to their signs and symptoms. The vascular type (type IV) has an associated shortened life expectancy because of rupture of

vessels and organs. A single case of EDS has been reported as simulating nonaccidental injury of child abuse.[89] In a similar manner, a single case of recurrent SDH in a 15-year-old child with EDS type IV was reported by Ortiz Remacha et al.[90]

Osteogenesis imperfecta is an inherited connective disuse disorder where the basic defect is the abnormal synthesis of the α_1 and α_2 chains of type I collagen. There are four types (with subclasses), with each type defined by its genetic abnormality or clinical features.[91] Osteogenesis imperfecta is a recognized diagnostic pitfall in the investigation of apparent nonaccidental injury, especially when considering the interpretation of recurrent skeletal fractures.[92] Scanty publications report a number of cranial pathologies, including intracranial bleeds, which have been associated with OI.[93] Tokoro et al.[94] reported a single nonfatal case of chronic SDH in a baby girl, which they attributed to rupture of the bridging veins during normal molding of the skull bones during delivery. They hypothesize that the chronicity of their cases may have been associated with other factors associated with OI, including coagulopathies and increased vascular fragility. This vascular fragility is caused by abnormal collagen support around the vessels and can be demonstrated by a positive Rumpel-Leede capillary fragility test. In a series of 79 patients with OI presented by McAllion, vascular fragility was also considered a significant factor in the causation of intracranial hemorrhage of all types, at all ages.[95] Osipenkova and Trakhtenberg[95] presented a single fatality in a 6-month-old infant with OI, SDH, and subarachnoid hemorrhage that was attributed to the trauma from bumping of the child's head against a wall.[95]

Minor trauma as a cause of SDH and retinal hemorrhages in individuals with OI was presented in a series of three children by Ganesh et al.[96] All three children had type I OI and, following through investigation, all three cases were considered accidental in nature. The principle author (G.R.) has encountered a fatal case of type I OI that presented with recurrent rib and long bone fractures, skin bruising, SDH, and retinal hemorrhages. Following full police investigation, this case ultimately was considered nonsuspicious in nature. These cases illustrate the diagnostic dilemma facing the investigating authorities as to whether these cases are patients with spontaneous or accidental pathologies in association with OI or cases of abuse of patients with OI.

Vitamin Deficiencies

Subdural hematomas may occur in childhood with vitamin C, and K abnormalities. No reports exist of SDH with vitamin A, B, or E abnormalities. A single case related to vitamin D deficiency is discussed in the following.

The majority of papers on the association of SDH and vitamin deficiency/abnormalities relate to vitamin K. This finding may be the result of either maternal vitamin K deficiency with SDH arising in the developing fetus[97] or postdelivery neonatal vitamin K deficiency known as *hemorrhagic disease of the newborn* (HDN). As reported by Rutty et al.,[98,99] HDN may be delayed beyond the immediate postnatal period and may present with both SDH and retinal hemorrhages, mimicking nonaccidental injury.

Only one paper related to vitamin C deficiency could be identified to date. In this report, both SDH and retinal hemorrhages are hypothesized to result from a combination of ascorbate depletion and injection of foreign protein (from vaccinations) leading to exceptionally high blood histamine level. This situation in turn was hypothesized to result in capillary fragility and venous bleeding.[100]

To date no definite cases of subdural hematomas occurring in children in association with vitamin D deficiency have been reported. However, a single case of a 2.5-year-old Bengali male child with rickets who underwent bilateral exploratory burr holes to both the frontal and parietal bones because of clinical suspicion of SDH has been reported, although only 15 ml of clear fluid to the left frontal burr hole was found.[101]

Therapeutic Drugs

A case of an 8-month-old male infant who had severe hepatotoxicity from phenobarbital toxicity was reported by Roberts et al.[102] This child presented with a severe seizure-like episode and collapse, the cause of which was attributed to bilateral chronic SDH. Unfortunately this paper does not enlighten the reader as to the clinical cause of the SDH but rather concentrates on the complications related to phenobarbital treatment.[102]

Vascular Disease, Malformations, and Flow Abnormalities

Subdural hematomas may occur in children as a presenting symptom of vascular disease or vascular malformations.

Kawasaki disease is a multisystem disorder characterized by vasculitis of small and medium arteries. Neurologic complications, including meningoencephalitis, monocyte-predominant pleocytosis in the CSF, facial nerve palsy, seizures, hemiplegia, and sensorineural hearing loss have been reported to occur in 1.1% to 3.7% of affected children.[103–105] Two papers detailing seven cases of SDH in children as young as 6 months have been reported.[106,107] The SDH in these cases was hypothesized to be caused by vasculitis of dural vessels. All cases reported to date have been in living subjects with no fatalities or for whom postmortem findings had been reported.

Intracranial arteriovenous malformations (AVM) and cavernous hemangioma are rare causes of neonatal intracranial haemorrhage.[108] Neonatal subdural hemorrhage in association with AVM appears to have been reported only four times in the literature, although the principal author (G.R.) has dealt with a nonreported fatal case of SDH associated with a subtentorial meningeal AVM that initially was suspected to be a nonaccidental injury.

Cerebral aneurysms have a distinct male predominance (12:1), occurring most frequently in the distal middle cerebral artery distribution or the posterior circulation.[109] They also have a higher incidence of large/giant aneurysms compared to adults. They are associated with head and birth trauma, infection (mycotic), fibromuscular dysplasia, moyamoya disease, coarctation of the aorta, subacute bacterial endocarditis, collagen vascular disease, EDS, Marfan syndrome, syphilis, sickle cell anemia, and tuberous sclerosis. Rupture of the aneurysm may occur, resulting in intracranial hemorrhage. The case of a 7-month-old boy with SDH in association with a cluster of six basilar artery aneurysms was reported by Plunkett.[110]

Congenital Heart Disease

Despite technical advances, neurologic complications of open heart surgery are estimated to occur in up to 24% of cases.[111] The association between SDH and congenital heart disease (CHD) in infants is related to surgery and the postoperative period rather than a complication of untreated CHD. Humphreys et al.[112] drew

attention to intracranial hemorrhage occurring in children following open heart surgery for CHD, most frequently valve or congenital cyanotic heart operations. In their series of 16 cases, 11 had SDH. Bleeds varied from "small localised area of haemorrhage" to "a clot occupying an entire hemicranium." They then postulated that the SDH resulted from low arterial perfusion pressure and brain shrinkage with tearing of the surface bridging veins. Other authors have favored preoperative coagulopathies as the cause of SDH.

Complications of Medical/Surgical Treatment

The best-known association between SDH and medical/surgical treatment is noted with shunting for hydrocephalus. This complication was first reported by Anderson[113] in 1952. It occurs more frequently in children with normal-pressure hydrocephalus (20%–46%) than in those with hypertensive hydrocephalus (0.4%–5%). Those with hydrocephalus secondary to vein of Galen malformations have an incidence up to 10%.[114]

The cause of the SDH has been related to excessive drainage of CSF resulting in a combination of collapse of the brain and opening of the subdural space[115] and tearing of the bridging veins. Fifty-eight percent of all cases are asymptomatic.

There is a single report of SDH complicating endoscopic III ventriculoscopy in a 2-year old-male child. In this case report, Maeda et al.[116] hypothesize that the blood arose from the wound site or from bridging vein injury resulting from acute decompression of the hydrocephalus.

Finally, a case of a 2.5-year-old female child who developed SDH following encephalo-myo-synangiosis (EMS) was reported by Sonobe et al.[117] The girl had right hemiparesis as a result of a very narrow left carotid artery bifurcation and small vessels as a result of moyamoya. EMS led to improvement of her hemiparesis, but she subsequently represented with ipsilateral SDH attributed to a complication of the EMS.

Metabolic Disease

Garrod[118] was the first in 1909 to use the term *inborn errors of metabolism* to describe a spectrum of genetically inherited disorders characterized by deficient activity of an enzyme in a metabolic pathway. The subject was visited by Olpin and Evans[119] in *Essentials of Autopsy Practice* (Volume 2), in which neurologic complications of a number of metabolic disorders were described. Of these disorders, glutaric aciduria type 1 (GA1) is the most commonly misinterpreted as nonaccidental injury because one of its presenting features may be SDH.

GA1 is an autosomal recessive inborn error of metabolism that can produce mild-to-moderate macrocephalus.[120] In the presence of frontotemporal atrophy the bridging veins are abnormally elongated and vulnerable to damage during minor injury, leading to both SDH and retinal hemorrhages (via subarachnoid effusion).[121–123] The most common presenting age group consists of those 7 to 18 months old, but presentation in the immediate postnatal period has also been reported. Examination reveals multiple SDH of differing ages[124] that may be unilateral or bilateral, with the latter being more common.[125]

Another neurometabolic condition that has been reported in association with SDH is D-2-hydroxyglutaric aciduria (D-2-HG). The genetic transmission and pathway abnormality for this disorder remain poorly defined.[126] In a single case report, a 7-month-old male child with macrocephaly and cerebral atrophy presented

with a unilateral right SDH with normal retinas. Again, the cause of the SDH is attributed to stretching of the bridging veins because of the increase in head size with associated cerebral atrophy.

A single case of a 5-week-old female child who had SDH and retinal hemorrhages in association with methylmalonic aciduria and homocystinuria has been reported. The cause of this abnormality is cobalamin C deficiency. These cases suffer from microcephaly and not macrocephaly, so the authors rejected a traumatic bridging vein abnormality. Rather they hypothesized that the raised levels of homocysteine cause direct vascular endothelial damage resulting in spontaneous haemorrhage.[127]

In 1962 Menkes[128] described a lethal neurodegenerative disorder. Menkes disease is an X-linked recessive disorder located on chromosome X13.3, which encodes for a copper-transporting P0type ATPase. The resulting abnormality of copper absorption results in a number of systemic abnormalities and is associated with SDH.

Vaccines

In recent years, particularly in the United States, vaccinations, specifically the diphtheria, tetanus, and pertussis (DTP) combined vaccination, have been postulated as a mimic of shaken baby syndrome. An autoimmune mechanism for cerebral injury has been speculated but, unlike pathology that may occur with rabies vaccination, no such mechanism has been demonstrated or proved with the DTP vaccine.[129]

A combined vaccine that has been reported to have a causal relationship with idiopathic thrombocytopenic purpura (ITP) is the mumps, measles, rubella (MMR) vaccine. Miller et al.[130] estimate that the absolute risk of developing ITP within 6 weeks of receiving the MMR vaccine is 1 in 22,300 doses. However, none of the cases presented in their paper had evidence of SDH.[130]

Thus, to date no peer-reviewed papers have demonstrated a categorical causal link between vaccinations and SDH. In the paper by Clementson (discussed in the section on vitamin deficiencies), the author hypothesizes a link between vaccinations, vitamin C deficiency, abnormal histamine levels, and SDH but presents no research-based evidence supporting the theory. A second theoretical paper on the subject, also authored by Clementson,[131] again postulates that inoculations cause a variant of infantile scurvy (Barlow disease). Although he again argues that vascular fragility may led to SDH and retinal hemorrhages during the normal handling of a child following inoculations, he presents no raw data or peer-reviewed research supporting his theory.

Calcified Subdural Hematoma

Calcified SDH has been reported in association with postmeningitic SDH effusion and as a long-term complication of ventriculoperitoneal shunts. It can be unilateral or bilateral and may undergo ossification. It may produce the so-called *armored brain appearance.* It rarely is symptomatic and more usually is asymptomatic.[132]

Alagille Syndrome

Alagille syndrome is a congenital absence of bile ducts in the liver. It is quoted as a cause of SDH, and yet no peer-reviewed paper could be identified to associate the two conditions.

School Age and Juveniles

Arachnoid Cysts

Arachnoid cysts are congenital lesions resulting from meningeal maldevelopment.[133] They occur most frequently within the middle fossa, usually unilaterally, with left-sided predominance (left to right 1.8:1) and male predominance (3:1). They are associated with SDH, subdural hygroma, and intracystic hemorrhage in teenage children, although cases in children as young as 5 years have been reported. Although the exact source of the SDH remains unknown, attention has centered on the unsupported bridging veins that traverse the cyst and fragile leptomeningeal vessels found within the cyst wall.[134] Two mechanisms have been hypothesized for the SDH: traumatic and spontaneous. The majority of SDH follows minor head trauma, when either traumatic cyst rupture or bridging vein injury is hypothesized to occur.[135,136] During the recovery phase, formation of unstable internal capillaries and sinusoids within the cyst wall may lead to chronic SDH as the result of repeated bleeds from these fragile vessels.[137] Spontaneous cyst rupture with associated SDH has been hypothesized to be caused by two mechanisms:

- Raised intracranial pressure, as may occur with a Valsalva maneuver
- Raised intracystic pressure resulting from increased flow of CSF into the cyst because of traumatic valve flap communication with the subarachnoid space such that it distends and ruptures[138]

Bone Marrow Transplant

There is a recognized significant risk of morbidity and mortality from neurologic complications following bone marrow transplant (BMT). Subdural hematoma has been reported to occur in up to 12% of patients (all ages), with 75% diagnosed at autopsy without antemortem clinical symptoms.[139] Although more commonly occurring in adult BMT patients, SDH has been reported in children as young as 4 years.[140] They usually are unilateral in nature, randomly distributed, and variable in size.[141] Although the mechanism underlying the cause of the SDH remains unknown, there is an association with pretransplant thrombocytopenia and/or coagulopathy.

Traumatic Causes of Subdural Hematoma in Children

Several studies have shown that the majority of SDH in infants is the result of trauma.[142,143] Within this group, more cases result from inflicted than accidental trauma. Feldman et al.[144] identified inflicted trauma in 59% and accidental trauma in 23% of their series. Figures in a report from the Royal College of Paediatrics and Child Health estimated that 51% of infantile SDH results from inflicted trauma.[1] The association of SDH and abuse in infants has been known for a long time, first recorded by Tardieu in 1860.

The distinction of accidental from nonaccidental traumatic causes is of great importance in forensic work and frequently is demanded of forensic pathologists. This distinction depends on a number of factors, including social investigations. It is impossible for the pathologist to make this distinction, particularly when only

intracranial injury is present. In other words, no pathologist or neuroradiologist can diagnose "intent."

Pathogenesis of Traumatic Acute Subdural Hemorrhage

There are four possible origins of subdural hemorrhage:

1. Traumatic subdural hemorrhage usually results from tearing of the draining veins as they cross the subarachnoid and subdural spaces to enter the sagittal sinus.[5] These veins are large, and traumatic rupture leads to a thick subdural blood clot. This pattern is typical of infants older than 9 months and adults.[144,145] The majority of SDH in young infants is thin fluid, which is readily tapped, rather than dense clot.[18]
2. Subdural hemorrhage may result from tentorial tearing, which is associated with molding of the head and movement of the skull bones, usually during delivery.
3. Thin-film subdural hemorrhage may result from oozing of blood from dural and arachnoid vessels in conditions where there is hypoxic endothelial damage together with raised intracranial vascular pressure. This is consistent with the recognized vascularity of the dura and the frequency of intradural bleeding in infants following asphyxia.[9]
4. Bleeding may into the subdural space from a bleed in another intracerebral compartment, after rupture of an aneurysm,[5,146] or following arachnoid tear.[18,147]

Causes of Traumatic Subdural Hematoma

As noted at the beginning of the chapter, the majority of infant SDH is the result of trauma, of which inflicted injury is the most frequent cause. Proposed mechanisms of such injury are highly contentious. Although severe high-velocity impact, such as motor vehicle accidents and falls from great heights, undoubtedly can cause SDH, very little is known about the effects of much lesser forces.

Direct trauma or impact causes deformation of the skull, with or without fractures, contusion, and epidural and subdural hemorrhage. Angular or rotational acceleration or deceleration of the head on the neck occurs in whiplash and shaking injuries, although there also is a rotational element in most falls as a result of hinging of the head on the neck. These forces are more likely to cause shearing injuries of the intracranial structures.[148,149] However, all mechanisms – translational, rotational, and angular – can cause subdural hematoma.

Shaking

More than 30 years ago a hypothesis was proposed to explain subdural hemorrhages in infants thought to have been abused.[150] This hypothesis proposed that shaking could cause brain damage and tearing of the draining veins of the brain leading to subdural hemorrhage. However, biomechanical studies using animals and models have indicated that the forces required are enormous, about 20 times those attainable by fit young adult volunteers.[151] Further, and more recently, model studies indicate that impact generates far more force than shaking alone[152] and that impact is required to produce SDH.[147] The degree of force (or violence) required to damage an infant is unknown, but it is noteworthy that healthy adult volunteers fatigued

after shaking an infant model for 10 seconds.[153] These authors suggested that impacting of the infant head/chin against the chest or the upper back during shaking might produce a contributory impact. In any infant who may have been violently shaken, injury to the ligaments, muscles, and nerves of the neck and of the cervical spinal cord would be expected.[144,153,154]

However, there is one further suggested mechanism by which a baby's brain may be damaged by shaking or whiplash. The pathologic studies of Geddes et al.[144,145] showed that most infants with inflicted traumatic brain injury had suffered lack of blood or oxygen supply to the brain. One third had torn nerve fibers in the part of the brainstem (craniocervical junction) where the respiratory control centers are found. The authors suggested that damage here would cause a baby to stop breathing, which would lead to a cascade of events resulting in brain swelling and retinal and possibly subdural hemorrhages. However, this mechanism depends on producing apnea (cessation of breathing) and subsequent severe brain swelling. This hypothesis has been rejected by some[155] and further emphasizes the importance of careful examination of the spinal cord and craniocervical junction in all infants with SDH. Readers are drawn to the Court of Appeal transcripts related to R v Harris, Rock, Cherry and Faulder where consideration is given to the controversies surrounding the pathology and causation of SDH in so-called shaken baby syndrome.[158a]

Low-Level Falls

Low-level falls can, albeit extremely rarely, cause SDH in infants and young children. Absolute height is not as important a criterion for injury as the following:

- *Exact nature of the fall* (What was the fall distance? Was it a free fall?)
- *For a particular infant* (What was the weight? Was the infant standing at the start of the fall? Which part of the body hit the surface?)
- *In a particular circumstance* (What was the nature of the landing surface? Did the body roll and dissipate the force?)

The effects of twisting, rotation, or crushing of the structures of the neck are crucial to outcome. It is well recognized that infants frequently tumble and fall, and fortunately in the majority of cases they suffer little ill effect. However, many studies show that low-level falls *can* cause serious intracranial injury, so they cannot be dismissed out of hand.

Biomechanical studies show that falls even from low levels of 3 to 4 feet can generate far greater forces in the head than impulsive action (or shaking).[150] Plunkett[156] and Kim et al.[157] have reported series demonstrating that children may suffer considerable intracranial damage after falls from levels as low as 6 feet. Patients in Plunkett's series were all older than 1 year. However, other papers have recorded intracranial bleeding in infants younger than 5 months who fell from less than 5 feet.[158] Schloff et al.[159] included four babies older than 6 weeks who fell less than 8 feet and developed intracranial hemorrhage. Single cases also have been reported. Aly-Hamdy et al.[160] described a baby who fell 3 feet onto a carpeted floor and developed subdural and retinal hemorrhages. Thus, although most children and infants may suffer little from an apparently trivial fall, it is clearly well recognized that minor low-level falls can cause intracranial bleeding, including subdural and retinal hemorrhages.

Localization of Subdural Hematoma

Most traumatic SDH is found in the parafalcine region close to the sites of insertion of draining veins. Localization depends on age and, as noted earlier, in infants the hemorrhage often is widespread over the convexities and thin. Postnatal SDH is seen far more commonly in the posterior fossa. Ewings-Cobbs et al.[161] found interhemispheric hemorrhage in most of their cases and always in association with convexity hemorrhage, never in isolation. Vinchon et al.[3] found a similar high incidence of parafalcine bleeding, especially in infants with signs of brain swelling. The falx is commonly hemorrhagic in asphyxiated infants,[9] indicating that, in some cases at least, imaging may be showing intrafalcine congestion and bleeding rather than parafalcine subdural hemorrhage.

Neuroradiologic studies have further suggested that localization of SDH can distinguish between inflicted and accidental SDH.[146,147] These studies state that posterior interhemispheric parasagittal and posterior fossa SDH are more likely to result from inflicted injury. However, the figures reported by Ewings-Cobbs et al.[161] demonstrate that the location of SDH is related to age. In infants younger than 1 year, there is no difference in localization of intracranial hemorrhage between infants with inflicted or accidental trauma. Vinchon et al.[18] reinforced this finding and stated that only the presence of retinal hemorrhages was of any assistance in distinguishing inflicted from accidental trauma.

It is hard to explain posterior fossa hemorrhage by shaking. The draining veins of the cerebellum would not likely be torn by rotational forces given their anatomy, as they run deep at the base of the cerebellum, close to the fulcrum of the craniocervical junction, not at its distal most equator. Nor would the close confinement of the cerebellum within the posterior fossa permit much movement to generate great stresses on its draining veins.

Summary

Although abusive head trauma remains the most common cause of SDH in children, the mechanisms remain under investigation and the subject of debate within the medical literature. When investigating a child with SDH, remember that trauma is not the only cause of SDH, and an extensive, often time-consuming, exhaustive investigation into all the causes considered in this chapter must be undertaken if the real cause is to discovered at the end of the day.

References

1. Hobbs C, Wynn J, Livingston J, Childs AM, Seal A. Subdural haematoma/effusion (SDH). RCPCH 14th Annual Report 1999–2000. London: British Paediatric Surveillance Unit, 2000:40–41.
2. Parent AD. Pediatric chronic subdural hematoma: a retrospective comparative analysis. Pediatr Neurosurg 1992;18:266–271.
3. Vinchon M, et al. Subduroperitoneal drainage for subdural hematomas in infants: results in 244 cases. J Neurosurg 2001;95:249–255.
4. Haines DE, Harkey HL, al Mefty O. The "subdural" space: a new look at an outdated concept. Neurosurgery 1993;32:111–120.
5. Leestma JE. Impact injuries to the brain and head. Forensic neuropathology. New York: Raven Press, 1988:184–253.

6. Aoki N, Mizutani H, Masuzawa H. Unilateral subdural-peritoneal shunting for bilateral chronic subdural hematomas in infancy. Report of three cases. J Neurosurg 1985;63:134–137.
7. Vinchon M, Defoort-Dhellemmes S, Noule N, Duhem R, Dhellemmes P. Accidental or non-accidental brain injury in infants. Prospective study of 88 cases. Presse Med 2004;33:1174–1179.
8. Parent AD. Pediatric chronic subdural haematoma: a retrospective comparative analysis. Pediatr Neurosurg 1992;18:266–271.
9. Friede RL. Hemorrhages in asphyxiated premature infants. In: Friede R, editor. Developmental neuropathology. Gottingen: Springer-Verlag, 1989:44–58.
10. Yamashima T. The inner membrane of subdural hematomas. Neurosurg Clin N Am 2000;11: 413–423.
11. Sherwood D. Chronic subdural hematoma in infants. Am J Dis Child 1930;39:980.
12. Hwang SK, Kim SL. Infantile head injury, with special reference to the development of chronic subdural hematoma. Childs Nerv Syst 2000;16:590–594.
13. Uscinski R. Shaken baby syndrome: fundamental questions. Br J Neurosurg 2002;16:217–219.
14. Ito H, Yamamoto S, Komai T, Mizukoshi H. Role of local hyperfibrinolysis in the etiology of chronic subdural hematoma. J Neurosurg 1976;45:26–31.
15. Markwalder TM. Chronic subdural hematomas: a review. J Neurosurg 1981;54:637–645.
16. Swift DM, McBride L. Chronic subdural hematoma in children. Neurosurg Clin N Am 2000;11: 439–446.
17. Kobayashi M, Toshinami N, Maeda T, Ito K, Hisada K. "[Post-meningitis subdural hygroma in a child showing abnormal RI accumulation in 169Yb-DTPA RI cisternography]." Kaku Igaku 1976;13:553–557.
18. Vinchon M, Defoort-Dhellemmes S, Noule N, Duhem R, Dhellemmes P. Accidental or non-accidental brain injury in infants. Prospective study of 88 cases. Presse Med 2004;33:1174–1179.
19. Whitby EH, Griffiths PD, Rutter S, et al. Frequency and natural history of subdural haemorrhages in babies and relation to obstetric factors. Lancet 2004;363:846–851.
20. McArdle CB, Richardson CJ, Hayden CK, Nicholas DA, Crofford MJ, Amparo EG. Abnormalities of the neonatal brain: MR imaging. Part 1. Intracranial hemorrhage. Radiology 1987;163:387–394.
21. Green PM, Wilson H, Romaniuk C, May P, Welch CR. Idiopathic intracranial haemorrhage in the fetus. Fetal Diagn Ther 1999;14:275–278.
22. Sherer DM, Anyaegbunam A, Onyeije C. Antepartum fetal intracranial hemorrhage, predisposing factors and prenatal sonography: a review. Am J Perinatol 1998;15:431–441.
23. Akman CI, Cracco J. Intrauterine subdural hemorrhage. Dev Med Child Neurol 2000;42:843–846.
24. Evans M-J. Birth injury and instrumental deliveries. In: Rutty GN, editor: Essentials of autopsy practice, vol 1. London: Springer, 2001:123–126.
25. Pollina J, Dias M, Li V, Kachurek D. Cranial birth injuries in term newborn infants. Pediatr Neurosurg 2001;35:113–119.
26. Hayashi T, Hashimoto T, Fukuda S, Ohsima Y, Mortaka K. neonatal subdural hematoma secondary to birth injury. Clinical analysis of 48 survivors. Childs Nerv Syst 1987;3:23–39.
27. Chamnanvanakij S, Rollins N, Perlman JM. Subdural hematoma in term infants. Pediatr Neurol 2002;26:301–304.
28. Hovind KH. traumatic birth injuries. In: Raimondi AJ, Choux M, DiRocco C, editors. Head injuries in the newborn and infant. New York: Springer, 1986:87–109.
29. Towner D, Castro M.A, Eby-Wilkens E, Gilbert WM. Effect of mode of delivery in nulliparous women on neonatal intracranial injury. N Engl J Med 1999;341:1709–1714.
30. Wen SW, Lui S, Kramer MS, et al. Comparison of maternal and infant outcomes between vacuum extraction and forceps deliveries. Am J Epidemiol 2001;153:103–107.
31. Hankins GDV, Leicht T, van Hook J, Uckan E. The role of forceps rotation in maternal and neonatal injury. Am J Obstet Gynecol 1999;180:231–234.
32. Hernansanz J, Munoz F, Rodriguez D, Soler C, Principe C. Subdural hematomas of the posterior fossa in normal-weight newborns. Report of two cases. J Neurosurg 1984;61:972–974.
33. Menezes AH, Smith DE, Bell WE. Posterior fossa hemorrhage in the term neonate. Neurosurgery 1983;13:452–456.
34. Hanigan WC, Morgan AM, Kokinski L, Stahlberg MS, Hiller JL. Tentorial hemorrhage associated with vacuum extraction. Pediatrics 1990;85:534–539.
35. Jhawar BS, Ranger A, Steven D, Del Maestro RF. Risk factors for intracranial hemorrhage among full-term infants: a case-control study. Neurosurgery 2003;52:581–590.
36. Rutherford M. Magnetic resonance imaging of injury to the immature brain. In: Squier W, editor. Acquired damage to the developing brain timing and causation. London: Arnold, 2002:166–192.
37. Govaert P, Vanhaesebrouck P, de Praeter C. Traumatic neonatal intracranial bleeding and stroke. Arch Dis Child 1992;67:840–845.

38. Steinbok P, Haw CS, Cochrane DD, Kestle JR. Acute subdural hematoma associated with cerebral infarction in the full-term neonate. Pediatr Neurosurg 1995;23:206–215.
39. Tuthill D.P, Samuel L, Morris S, Drayton M. Neonatal subdural transudation of total parietal nutrition. J Pediatr Gastroenterol Nutrition 1998;27:359–361.
40. Prader A, Labhart A. Willi H. Ein syndrome von adipositas, klein-wuchs, kryptorchismus und oligphrenie nach myatonieartigem zustand in neugeborenenalter. Schweiz Med Wochenschr 1956;86:1260–1261.
41. Klinge L, Scott RC, de Sousa C. neonatal subdural and extradural haemorrhage in Prader-Willi syndrome. Neuropediatrics 2001;32:221–222.
42. Perrin RG, Rutka JT, Drake JM, et al. Management and outcomes of posterior fossa subdural hematomas in neonates. Neurosurgery 1997;40:1190–1200.
43. Ries M, Wolfel D, Maier-Brandt B. Severe intracranial hemorrhage in a newborn infant with transplacental transfer of an acquired factor VIII:C inhibitor. J Pediatr 1995;127: 649–650.
44. Michaud JL, Rivard G-E, Chessex P. Intracranial hemorrhage in a newborn with hemophilia following elective cesarean section. Am J Pediatr Haematol Oncol 1991;13:473–475.
45. Bray GL, Luban NLC. Hemophilia presenting with intracranial hemorrhage. Am J Dis Child 1987;141:1215–1217.
46. Pettersson H, McClure P, Fitz C. Intracranial hemorrhage in hemophilic children. Acta Radiol Diagn (Stockholm) 1984;25:161–164.
47. Yue CP, Mann KS. The surgical management of intracranial hematomas in hemophiliac children. Childs Nerv Syst 1986;2:5–9.
48. Ohga S, Kajiwara M, Toubo Y, et al. Neonatal hemophilia B with intracranial hemorrhage. Case report. Am J Pediatr Hematol Oncol 1988;10:244–248.
49. Yoffe G, Buchanan G.R. Intracranial hemorrhage in newborn and young infants with hemophilia. J Pediatr 1988;113:333–336.
50. Klinge J, Auberger K, Auerswald G, et al. Prevalence and outcome of intracranial haemorrhage in haemophiliacs: a survey of the pediatric group of the German Society of Thrombosis and Haemostasis (GTH). Eur J Pediatr 1999;158(suppl 3):S162–S165.
51. Almaani WS, Awidi AS. Spontaneous intracranial bleeding in hemorrhagic diathesis. Surg Neurol 1982;17:137–140.
52. Gill FM. Thrombocytopenia in the newborn. Semin Perinatol 1983;7:201–212.
53. Thomas A, Stirling D. Four factor deficiency. Blood Coagul Fibrinolysis 2003;14(suppl 1): S55–S57.
54. Salooja N, Martin P, Khair K, Leisner R, Hann I. Severe factor V deficiency and neonatal intracranial haemorrhage: a case report. Haemophilia 2000;6:44–46.
55. Nicholls J, Chan LC, Koo YM, Kwong YL, Tsoi NS. Subdural haematoma and factor XII deficiency in a Chinese infant. Injury 1993;24:202–203.
56. Larsoe PD, Wallace JW, Frankel LS, Crisp D. Factor XIII deficiency and intracranial hemorrhages in infancy. Pediatr Neurol 1990;6:277–278.
57. Russell-Eggitt IM, Thompson DA, Khair K, Liesner R, Hann IM. Hermansky-Pudlak syndrome presenting with subdural haematoma and retinal haemorrhages in infancy. J R Soc Med 2000; 983:591–592.
58. Al-Fawaz IM, Gader AMA. Severe congenital dysfibrinogenemia (Fibrinogen-Riyadh): a family study. Acta Haematol 1992;88:194–197.
59. Falter ML, Sutton AL, Robinson MG. Massive intracranial hemorrhage in sickle-cell anemia. Am J Dis Child 1973;125:415–416.
60. Ulbrych-Jablonska VA, Kalenik J. The role of toxoplasmosis for the development of lesions of the central nervous system in children. Zentralbl Neurochir 1980;41:31–36.
61. Omanga U, Shako D, Ntihinyurwa M, Mbuyu K, Beltchika K. A rare cause of subdural effusion in children: cerebral malaria. Ann Pediatiatr 1979;26:717–719.
62. Baliszewska B, Gietko M, Stembrowicz K. Subdural haematomas and hygromas in the course of toxic diarrhoea. Pediatr Pol 1970;45:537–542.
63. Kurtz J, Anslow P. Infantile herpes simplex encephalitis: diagnostic features and differentiation from non-accidental injury. J Infect 2003;46:12–16.
64. Zakoscielna L, Kazmierczak H, Zaborowski A. Subdural haematoma as a complication of chronic otitis media. Otolaryngol Pol 1987;41:228–231.
65. Levin M, Kay JDS, Gould JD, et al. Haemorrhagic shock and encephalopathy: a new syndrome with a high mortality in young children. Lancet 1983;2:64–67.
66. Ince E, Kuloglu Z, Akinci Z. Hemorrhagic shock and encephalopathy syndrome: neurologic features. Pediatr Emerg Care 2000;16:260–264.

67. Little D, Wilkins B. Hemorrhagic shock and encephalopathy syndrome. An unusual cause of sudden death in children. Am J Forensic Med Pathol 1997;18:79–83.
68. Mori K, Handa H. Subdural haematoma (effusion) and internal hydrocephalus. Neurochirurgia 1977;20:154–161.
69. Robertson WC, Chun RWM, Orrison WW, Sackett JF. Benign subdural collections of infancy. J Pediatr 1979;984:382–385.
70. Carolan PL, McLaurin RL, Towbin RB, Towbin JA, Egelhoff JC. Benign extra-axial collections of infancy. Pediatr Neurosci 1985–6;12:140–144.
71. Hamza M, Bodensteiner JB, Noorani PA, Barnes PD. Benign extracerebral fluid collections: a cause of macrocrania in infancy. Pediatr Neurol 1987;3:218–221.
72. Briner S, Bodensteiner J. Benign subdural collections of infancy. Pediatrics 1981;67:802–804.
73. Piatt JH. A pitfall in the diagnosis of child abuse: external hydrocephalus, subdural hematoma and retinal hemorrahages. Neurosurg Focus 1999;7:1–9.
74. Ravid S, Maytal J. External hydrocephalus: a probable cause for subdural hematoma in infancy. Pediatr Neurol 2003;28:139–141.
75. Papasian N, Frim DM. A theoretical model of benign external hydrocephalus that predicts a predisposition towards extra-axial hemorrhage after minor head trauma. Pediatr Neurosurg 200;33:188–193.
76. Pittman T. Significance of a subdural hematoma in a child with external hydrocephalus. Pediatr Neurosurg 2003;39:57–59.
77. Kumar S, Tatke M, Husain Z. Chordoid meningioma associated with chronic subdural hematoma. Indian Pediatr 1996;33:783–785.
78. Matsyama T, Aoyama N. A rare case of middle fossa neuroepithelial cyst accompanied by chronic subdural hematoma. No Shinkie 1993;21:931–933.
79. Bailey OT, Ingraham FD. Intracranial fibrosarcoma of the dura mater in childhood: pathological characteristics and surgical management. J Neurosurg 1945;2:1–15.
80. Cinalli G, Zerah M, Carteret M, et al. Subdural sarcoma associated with chronic subdural hematoma. Repot of two cases and review of the literature. J Neurosurg 1997;86:553–557.
81. Labalette P, Guilbert F, Jourdel D, Nelken B, Cuvellier J-C, Maurage C-A. Bilateral multifocal uveal juvenile xanthogranuloma in a young boy with systemic disease. Graefes Arch Clin Exp Ophthalmol 2002;240:506–509.
82. Sitton JE, Reimund EL. Extramedullary hematopoiesis of the cranial dura and anhidrotic ectodermal dysplasia. Neuropediatrics 1992;23:108–110.
83. Finberg L, Luttrell C, Redd H. Pathogenesis of lesions in the nervous system in hypernatremic states: II. Experimental studies of gross anatomic changes and alterations of chemical composition of the tissues. Pediatrics 1959;23:46–53.
84. Kempe CH, Silverman FN, Steele BF, Droegemueller W, Silver HK. The battered child syndrome. JAMA 1962;181:17–24.
85. Handy TC, Hanzlick R, Shields LBE, Reichard R, Goudy S. Hypernatremia and subdural hematoma in the pediatric age group: is there a causal relationship? J Forensic Sci 1999;44: 114–118.
86. Finberg L, Kiley J, Luttrell CN. Mass accidental salt poisoning in infancy. JAMA 1963;184:121–124.
87. Morcharla R, Schexnayder SM, Glasier CM. Fatal cerebral oedema and intracranial haemorrhage associated with hypernatraemic dehydration. Pediatric Radiol 1997;27:785–787.
88. Valik A, Rothova N, Jelinek J, Kesslerova Z. Subdural hemorrhage and effusion in infantile hypernatraemia: clinical and electroencephalographic study of two cases. Cas Lek Ces 1973;112: 232–237.
89. Owen SM, Durst RD. Ehlers-Danlos syndrome simulating child abuse. Arch Dermatol 1984;120: 97–101.
90. Ortiz Remacha PP, Candia J, Conde y M. Hemorragia subdural recurrent como forma de presentacion del syndrome de Ehlers-Danlos de tippo IV. Rev Clin Esp 2000;200:181–182.
91. Freemont AJ. The pathology of osteogenesis imperfecta. J Clin Pathol 1996;49:618.
92. Evans M-J. Mimics of non-accidental injury in children. In: Rutty GN, editor: Essentials of autopsy practice, vol. 1. London: Springer, 2001:134–135.
93. McAllion SJ, Paterson CR. Causes of death in osteogenesis impefecta. J Clin Pathol 1996;49: 627–630.
94. Tokoro K, Nakajima F, Yamataki A. Infantile chronic subdural hematoma with local protrusion of the skull in a case of osteogenesis imperfecta. Neurosurgery 1988;22:595–598.
95. Osipenkova TK, Trakhtenberg LIA. Fracture of the skeletal bones in incomplete osteogenesis. Sud Med Ekspert 1983;26:25–26.

96. Ganesh A, Jenny C, Geyer J, Shouldice M, Levin AV. Retinal hemorrhages in type I osteogenesis imperfecta after minor trauma. Ophthalmology 2004;111:1428–1431.
97. Hirose M, Akiyama M, Takakura K, Noda Y. Active Crohn disease with maternal vitamin K deficiency and fetal subdural hematoma. Obstet Gynecol 2001;988(5 pt2):919–921.
98. Rutty GN, Woolley A, Brookfield C, Shepherd F, Kitchen S. The PIVKA II test: the first reliable coagulation test for autopsy investigations. Int J Legal Med 2003;117:143–148.
99. Rutty GN. Smith CM, Malia RG. Late form haemorrhagic disease of the newborn: a fatal case report with illustration of investigations which may assist in avoiding the mistaken diagnosis of child abuse. Am J Forensic Med Pathol 1999;1:48–51.
100. Clemetson CAB. Elevated blood histamine caused by vaccinations and vitamin C deficiency may mimic the shaken baby syndrome. Med Hypotheses 2004;62:533–536.
101. Paterson CR. Vitamin D deficiency rickets simulating child abuse. J Pediatr Orthop 1981;1: 423–425.
102. Roberts EA, Speilberg SP, Goldbach M, Phillips MJ. Phenobarbital hepatotoxicity in an 8-month old infant. J Hepatol 1990;10:235–239.
103. Rosenfeld EA, Corydon KE, Shulman ST. Kawasaki disease in infants less than one year of age. J Pediatr 1995;126:524–529.
104. Terasawa K, Ichinose E, Matsuishi T, Kato H. Neurological complications in Kawasaki disease. Brain Dev 1983;5:371–374.
105. Takagi K, Umezawa T, Saji T et al. [Meningoencephalitis in Kawasaki disease]. No To Hattatsu 1990;22:429–435.
106. Aoki N. Subdural effusion in the acute stage of Kawasaki disease (mucocutaneous lymph node syndrome). Surg Neurol 1988;29:216–217.
107. Bailie NM, Hensey OJ, Ryan S, Allcut D, King MD. Bilateral subdural collections-an unusual feature of possible Kawasaki disease. Eur Pediatr Neurol J 2001;5:79–81.
108. Young WF, Pattisapu JV. Ruptured cerebral aneurysm in a 39-day infant. Clin Neurol Neurosurg 2000;102:140–143.
109. Tekkok IH, Ventureyra EC. Spontaneous intracranial hemorrhage of structural origin during the first year of life. Childs Nerv Syst 1997;13:154–165.
110. Plunkett J. Sudden death in an infant caused by rupture of a basilar artery aneurysm. Am J Forensic Med Pathol 1999;20:211–214.
111. Menache CC, du Plessis AJ, Wessel DL, Jonas RA, Newburger JW. Current incidence of acute neurologic complications after open-heart operations in children. Ann Thorac Surg 2002;73: 1752–1758.
112. Humphreys RP, Hoffman HJ, Mustard WT, Trusler GA. Intracranial hemorrhage complicating surgery of congenital heart disease. Trans Am Neurol Assoc 1973;988:165–167.
113. Anderson FM. Subdural hematoma, a complication of operation for hydrocephalus. Pediatrics 1952;10:11–18.
114. Aguiar PH, Shu EB, Freitas AB, Leme RJ, Miura FK, Marino R Jr. Causes and treatment of intracranial haemorrhage complicating shunting for paediatric hydrocephalus. Childs Nerv Syst 2000;16:218–221.
115. Puca A, Fernandez E, Colosimo C, Lauretti L, Pallini R, Tamburrini G. hydrocephalus and macrocrania; surgical and nonsurgical treatment of postshunting SDH? Surg Neurol 1996; 45:376–382.
116. Maeda Y, Inamura T, Morioka T, Muratani H, Fukui M. hemorrhagic subdural effusion complicating an endoscopic III ventriculostomy. Childs Nerv Syst 2000;16:312–314.
117. Sonobe M, Takahashi S, Kubota Y, Shirane R. Chronic subdural hematoma developing after EMS for Moyamoya disease. No Shinkei 1982;10:857–859.
118. Garrod A.E. Inborn errors of metabolism. Oxford: Oxford University, Press 1909.
119. Olpin S, Evans M-J. The investigation of inherited metabolic disease after death. In: Rutty GN, editor: Essentials of autopsy practice: recent advances, topics and developments. London: Springer, 2003:17–44.
120. Morris AAM, Hoffmann GF, Naughten ER, Monavari AA, Collins JE, Leonard JV. Glutaric aciduria and suspected child abuse. Arch Dis Child 1999;80:404–405.
121. Morris AAM, Hoffmann GF, Naughten ER, Monavari AA, Collins JE, Leonard JV. Glutaric aciduria and suspected child abuse. Arch Dis Child 1999;80:404–405.
122. Woelfle J, Kreft B, Emons D, Haverkamp F. Subdural hemorrhage as an initial sign of glutaric aciduria type 1: a diagnostic pitfall. Pediatr Radiol 1996;26:779–781.
123. Schmidt LS, Nielson JEK, Blichfeldt SS, Lund AM. Metabolisk sygdom eller ruskevold? Ugeskr Laeyer 2003;165:3323–3324.

124. Osaka H, Kimura S, Nezu A, Yamazaki S, Saitoh K, Yamaguchi S. Chronic subdural hematoma, as an initial manifestation of glutaric aciduria type-1. Brain Dev 1993;15 125–127.
125. Twomey EL, Naughten ER, Donoghue VB, Ryan S. Neuroimaging findings in glutaric aciduria type 1. Pediatr Radiol 2003;33:823–830.
126. Kwong KL, Mak T, Fong CM, Poon KH, Wong SN, So KT. D-2-hydroxyglutaric aciduria and subdural haemorrhage. Acta Paediatr 2002;981:716–718.
127. Nassogne M-C, Sharrard M, Hertz-Pannier L, et al. Massive subdural haematomas in Menkes disease mimicking shaken baby syndrome. Childs Nerv Syst 2002;18:729–731.
128. Menkes JH, Alter M, Steingleder GK, Weakly DR, Sung JH. A sex-linked recessive disorder with retardation of growth, peculiar hair, and focal cerebral and cerebellar degeneration. Pediatrics 1962;29:764–769.
129. Chadwick DL, Parrish R. DTP vaccination or SBS? The role of irresponsible medical expert testimony in creating a false causal connection. Available at: http://www.partnersforimmunization.org/pdf/Vaccine_Safety.pdf
130. Miller E, Waight P, Farrington P, Andrews N, Stowe J, Taylor B. Idiopathic thrombocytopenic purpura and MMR vaccine. Arch Dis Child 2001;84:227–229.
131. Clementson CAB. Is it "shaken baby" or Barlow's disease variant? J Am Physicians Surg 2004;98:78–80.
132. Sharma RR, Mahapatra A, Pawar S, Sousa J, Athale SD. Symptomatic calcified subdural hematomas. Pediatr Neurosurg 1999;31:150–154.
133. Sener RN. Arachnoid cysts associated with post-traumatic and spontaneous rupture into the subdural space. Comput Medical Imaging Graphics 1997;21:341–344.
134. Parsch CS, Krau J, Hofmann E, Meixensberger J, Roosen K. Arachnoid cysts associated with subdural hematomas and hygromas: analysis of 16 cases, long-term follow-up and review of the literature. Neurosurgery 1997;40:483–490.
135. Kawanishi A, Nakayama M, Kadota K. heading injury precipitating subdural hematoma associated with arachnoid cysts. Neurol Med Chir 1999;39:231–233.
136. Donaldson JW, Edwards-Brown M, Luerssen TG. Arachnoid cyst rupture with concurrent subdural hygroma. Pediatr Neurosurg 2000;32:137–139.
137. Mori K, Yamamoto T, Horinaka N, Maeda M. Arachnoid cyst is a risk factor for chronic subdural hematoma in juveniles: twelve cases of chronic subdural hematoma associated with arachnoid cyst. J Neurotrauma 2002;19:1017–1027.
138. Gelabert-Gonzalez M, Fernandez-Villa J, Cutrin-Prieto J, Allut AG, Martinez-Rumbo R. Arachnoid cyst rupture with subdural hygroma: report of three cases and literature review. Childs Nerv Syst 2002;18:609–613.
139. Pomeranz S, Naparstek E, Ashkenazi E, Nagler A, Lossos A, Slavin S, Or R. Intracranial haematomas following bone marrow transplantation. J Neurol 1994;241:252–256.
140. Colosimo M, McCarthy N, Jayasinghe R, Morton J, Taylor K, Durrant S. Diagnosis and management of subdural haematoma complicating bone marrow transplantation. Bone Marrow Transplant 2000;25:549–552.
141. Bleggi-Torres LF, Werner B, Gasparetto EL, de Medeiros BC, Pasquini R, de Medeiros CR. Intracranial hemorrhage following bone marrow transplantation: an autopsy study of 58 patients. Bone Marrow Transplant 2002;29:29–32.
142. Jayawant S, Rawlinson A, Gibbon F, et al. Subdural haemorrhages in infants: population based study. BMJ 1998;317:1558–1561.
143. Feldman KW, Bethel R, Shugerman RP, Grossman DC, Grady MS, Ellenbogen RG. The cause of infant and toddler subdural hemorrhage: a prospective study. Pediatrics 2001;108:636–646.
144. Geddes JF, Vowles GH, Hackshaw AK, Nickols CD, Scott IS, Whitwell HL. Neuropathology of inflicted head injury in children. II. Microscopic brain injury in infants. Brain 2001;124(pt 7):1299–1306.
145. Geddes JF, Hackshaw AK, Vowles GH, Nickols CD, Whitwell HL. Neuropathology of inflicted head injury in children. I. Patterns of brain damage. Brain 2001;124(pt 7):1290–1298.
146. McLellan NJ, Prasad R, Punt J. Spontaneous subhyaloid and retinal haemorrhages in an infant. Arch Dis Child 1986;61):1130–1132.
147. Duhaime AC, Christian C, Moss E, Seidl T. Long-term outcome in infants with the shaking-impact syndrome. Pediatr Neurosurg 1996;24:292–298.
148. Barnes PD. Ethical issues in imaging nonaccidental injury: child abuse. Top Magn Reson Imaging 2002;13:85–93.
149. Guthkelch AN. Infantile subdural haematoma and its relationship to whiplash injuries. BMJ 1971; 2:430–431.

150. Ommaya AK, Goldsmith W, Thibault L. Biomechanics and neuropathology of adult and paediatric head injury. Br J Neurosurg 2002;16:220–242.
151. Cory CZ, Jones BM. Can shaking alone cause fatal brain injury? A biomechanical assessment of the Duhaime shaken baby syndrome model. Med Sci Law 200343:317–333.
152. Shannon P, Becker L. Mechanisms of brain injury in infantile child abuse. Lancet 2001; 358:686–687.
153. Hadley MN, Sonntag VK, Rekate HL, Murphy A. The infant whiplash-shake injury syndrome: a clinical and pathological study. Neurosurgery 1989;24:536–540.
154. Rutty GN, Squier WM, Padfield CJ. Epidural haemorrhage of the cervical spinal cord: a post-mortem artefact? Neuropathol Appl Neurobiol 2005;31:247–257.
155. Punt JAG, Bonshek RE, Jaspan T, McConachie NM, Punt N, Ratcliffe JM. The "unified hypothesis" of Geddes et al is not supported by the data. Pediatr Rehabil 2004;7:173–184.
156. Plunkett J. Fatal pediatric head injuries caused by short-distance falls. Am J Forensic Med Pathol 2001;22:1–12.
157. Kim KA, Wang MY, Griffith PM, Summers S, Levy ML. Analysis of pediatric head injury from falls. Neurosurg Focus 2000;8.
158. Greenes DS, Schutzman SA. Occult intracranial injury in infants. Ann Emerg Med 1998;32: 680–686.
158a. Court of Appeal judgment of R v Harris, Rock, Cherry and Faulder. Available at http://www.hmcourts-service.gov.uk/docs/r_v_harris.doc
159. Schloff S, Mullaney PB, Armstrong DC, et al. Retinal findings in children with intracranial hemorrhage. Ophthalmology 2002;109:1472–1476.
160. Aly-Hamdy N, Childs AM, Ferrie CD, Livingston JH. Subdural haemorrhage with bilateral retinal haemorrhage following accidental household trauma. BPNA 2002;24.
161. Ewing-Cobbs L, Prasad M, Kramer L, et al. Acute neuroradiologic findings in young children with inflicted or noninflicted traumatic brain injury. Childs Nerv Syst 2000;16:25–33.