JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, January 2017, Vol. 62, No. 1
doi: 10.1111/1556-4029.13219
Available online at: onlinelibrary.wiley.com

PAPER

PATHOLOGY/BIOLOGY

Serenella Serinelli,[1] M.D.; Ponni Arunkumar,[2] M.D.; James A. Filkins,[2] M.D., J.D., Ph.D.; and Lorenzo Gitto,[1] M.D.

Deaths Due to Child Abuse: A 6-Year Review of Cases in The Cook County Medical Examiner's Office

ABSTRACT: Case files from the Cook County Medical Examiner's Office from 2007 to 2012 were reviewed to analyze homicides due to physical child abuse in children <3 years old. Fatal cases mostly involved younger subjects. Intracranial injuries were the leading cause of death, while death due to extracranial injuries was uncommon. Eyes were involved in most of the cases. Spinal cord was involved in about 1/3 of the cases, mostly in the thoracic area. In some cases, previous injuries were present. There were significant differences in the pattern of injuries between age groups. Subjects showing signs of impact to the head and subjects with no evidence of an impact showed no significant difference in internal injuries. The association of multiple injuries is highly suggestive of child abuse. In suspected child abuse, a postmortem examination including neuropathological, ophthalmological, and radiological information should be always evaluated, together with investigative reports and the medical history.

KEYWORDS: forensic science, child abuse, homicide, intracranial findings, ocular hemorrhages, spinal cord injuries, abusive head trauma

Child abuse can be defined as "any recent act or failure to act on the part of a parent or caretaker which results in death, serious physical or emotional harm, sexual abuse or exploitation; or an act or failure to act, which presents an imminent risk of serious harm" (1).

Recent national statistics on child abuse (2) show that in 2013 approximately 679,000 children were victims of maltreatment, and approximately 1520 of them died. Children in the first year of their life had the highest rate of victimization of 23.1 per 1000 children in the national population of the same age. Of the children who experienced maltreatment or abuse, nearly 80% suffered neglect; 18% suffered physical abuse; and 9% suffered sexual abuse. In this study, we focus our attention on deaths due to physical abuse. which we have defined as intentionally inflicted pediatric injuries resulting in death.

Deaths due to child abuse can occur due to intracranial or extracranial injuries. Head injuries are the leading cause of death in abused young children, and extensive research has been published describing the epidemiology, patterns. and mechanisms of injury associated with pediatric abusive head trauma. There is a continuing debate about the mechanism of injury in pediatric abusive trauma; however, a discussion of the etiology of these injuries is beyond the scope of this paper. Here, we present an overview of the patterns of injury observed in a sample of children <3 years old who died as a result of physical abuse.

[1]Department of Anatomy, Histology, Forensic Medicine and Orthopedics, Sapienza–University of Rome, Viale Regina Elena 336, 00185 Rome, Italy.
[2]Cook County Medical Examiner's Office, 2121 W Harrison Street, Chicago, IL 60612.

Received 4 June 2015; and in revised form 3 Feb. 2016; accepted 21 Feb. 2016.

Methods

Population Selection

We searched the files of the Cook County Medical Examiner's Office in Chicago, Illinois, between 2007 and 2012 to identify deaths of children under 3 years old whose cause and manner of death was determined to be homicide due to child abuse. Each case was submitted to an Illinois Child Death Review Team, and no recommendation was made to amend a determination of "homicide" to "accident" or "undetermined." The data were retrospectively evaluated and analyzed. In our review, we collected data from autopsy reports and consultation reports from neuropathology, routine full body radiology (no CT and MRI studies were performed in any case) and ophthalmology. Detailed medical records were available in a few cases. All autopsies were performed by forensic pathologists at the Cook County Medical Examiner's Office, and neuropathological and ophthalmological consultations were obtained from local university-affiliated neuropathologists and ophthalmologists, respectively. The autopsy techniques used to remove the brain, spinal cord and eyes and the gross and microscopic examination of the nervous system were in accordance with standard techniques described in literature (3–9). In any case, the dorsal root ganglions were not dissected.

We then organized the data we obtained using Microsoft Excel® (Microsoft Corporation, Redmond, Washington, USA), with attention to the following parameters: sample size; age; sex; race; extracranial injuries; scalp and facial injuries; subgaleal hemorrhages (SGH); skull fractures; extradural, intradural and subdural hemorrhages (EDH, IDH, and SDH); subarachnoid hemorrhages (SAH); intracerebral and spinal cord findings; ocular findings; survival intervals; and resuscitative measures.

In order to compare deaths due to child abuse with accidental deaths in children of the same age and in the same time period, we also searched for the keyword "accident" as the manner of death in the Office's database.

Statistical Analysis

Outcome data, extracted from the medical reports, were imported into STATA 13 for statistical analysis. Chi-square test and Fisher's exact test were performed for the parameters, to compare groups as reported in the following paragraphs. A *p*-value was reported for each finding in the tables. Only *p*-values <0.05. considered to be statistically significant, were reported in the figures.

Results

Study Population

The sample consisted of 51 cases of homicide due to child abuse of subjects under 3 years old. None of the cases had positive medical history for infections, intracranial arteriovenous malformations, coagulopathies, metabolic or genetic disorders. As one of the aims of our analysis was to analyze the differences between younger and older subjects, we divided the population into two different age ranges: <12 months (referred to as "infants," $n = 26$) and 12–36 months (referred to as "toddlers," $n = 25$). The gender distribution was 26 males (11 infants and 15 toddlers) and 25 females (15 infants and 10 toddlers). Regarding race, there were 31 African American (14 infants and 17 toddlers) and 20 Caucasian (12 infants and 8 toddlers). Table 1 shows the pathological findings in these cases, comparing those in infants with those in toddlers.

Fatal Injuries Causing Death

Fatal abusive head trauma was the most common cause of death, occurring in 82.4% of the cases ($n = 42$). Death due to extracranial injuries alone accounted for the remaining 17.6% of the cases ($n = 9$). Of these, six subjects (all toddlers) died of abdominal injuries only, mostly liver and mesenteric lacerations. One died because of abdominal injuries and suffocation. Two others died of combined thoracic and abdominal blunt force injuries. Of these, one toddler had bilateral hemothoraces, left lung contusions, hemopericardium, right atrial laceration and thymic contusions and one infant presented with bilateral hemothoraces, visceral pleural hemorrhage, and thymic hemorrhage.

Autopsy Findings

General Autopsy Findings—The presence of bruises/abrasions/lacerations to the external surfaces of cranial vault or facial area, or SGH or skull fractures was observed in 82.4% of subjects ($n = 42$). External head and facial injuries were seen in 54.9% ($n = 28$) and 60.8% ($n = 31$) of subjects, respectively. SGH were observed in 70.6% ($n = 36$) of the cases. Skull fractures will be more fully discussed below.

Signs of neck impact (defined by the presence of bruises/abrasions/lacerations to the neck and/or muscular/ligamentous damages) were observed in 27.5% of subjects ($n = 14$).

Evidence of cutaneous and subcutaneous injuries (bruises, abrasions or lacerations) to the body with the exception of the head was present in 76.5% of the sample ($n = 39$). We found two cases with bite marks (located on the abdomen and the chest, respectively). Intra-abdominal injuries were observed in 33.3% of the cases ($n = 17$), all due to blunt force trauma, principally consisting of bleeding from hepatic and/or mesenteric lacerations. Intrathoracic injuries occurred in 25.5% of the cases ($n = 13$) and were mostly represented by lung contusions. Recent extracranial fractures (i.e. no evidence of callous formation) were present in 19.6% of the subjects ($n = 10$). A total of 14 recent extracranial fractures were observed in these ten subjects (right clavicle: 1; ribs: 8; right humerus: 1; right femur: 1; "tibial bucket handle": 2; right fibula: 1). Three subjects sustained simultaneous fractures. No spinal fractures were observed.

Previous Injuries—Evidence of previous (subacute and resolved) injuries to the head was seen in 21.6% ($n = 11$) of subjects. to the body in 51% ($n = 26$) and to both the head and body in 21.6% ($n = 11$). Among these. no previous skull fractures were detected. Older extracranial fractures were present in 27.5% of the subjects ($n = 14$). A total of 23 old fractures was observed (left scapula: 1; ribs: 11; left radius: 2; left ulna: 1; right radius: 1; right ulna: 1. right second metacarpal: 1; left femur: 2; right femur:1; left tibia: 1; right tibia: 1). Four subjects sustained fractures at multiple sites.

Skull and Brain Pathology—Skull fractures were present in 17.6% of cases ($n = 9$) and mainly affected the parietal bones, showing a linear appearance. They were limited to subjects <2 years of age. In six cases, the fractures extended across the suture lines to involve more than one bone. In three cases, they were bilateral and in two cases multiple. In six of the nine cases of skull fractures, no extradural hemorrhage was observed, but other intracranial injuries were present. Diastasis of the cranial sutures was present in 27.5% ($n = 14$).

Extradural hemorrhages was present in 19.6% of the cases ($n = 10$); eight of these were bilateral, IDH was found in 17.6% ($n = 9$). SDH was the most common intracranial finding, observed in 82.4% of cases ($n = 42$). Of these. 39 were acute SDH. Of the acute SDH, all involved the cerebral convexities, 28 were bilateral and 15 also involved the base of the brain. In three cases, the acute SDH was large enough to form a space-occupying lesion. We found 14 cases of older subdural bleeding defined as "old/organized/organizing." 11 in association with an acute SDH and three alone. Subarachnoid hemorrhage was present in about half the cases (27 of 51); of these, all involved the cerebral convexities, 23 were bilateral and 10 also affected the base of the brain.

Cerebral edema was present in 72.5% of subjects ($n = 37$). The most frequent microscopic finding in the brains was global hypoxia–ischemia, which was present in 37.3% of cases ($n = 19$), followed by focal areas of necrosis (27.5%, $n = 14$) and hemorrhage (15.7%, $n = 8$). No diffuse axonal injury (DAI) was detected, but β-APP (beta amyloid precursor protein) immunohistochemistry was not routinely performed in the Office during the selected period. The most commonly affected site was the brain (33.3%, $n = 17$), followed by the brainstem (13.7%, $n = 7$), and the cerebellum (7.8%. $n = 4$).

Spinal Cord Neuropathology—Spinal cord lesions were noted in 37.3% ($n = 19$) of the subjects. The most common finding was a thin layer of SDH over the cord. The thoracic area was

TABLE 1—*Comparison of the pathological findings in infants and toddlers.*

Findings		All (n = 51)	Perc. (%)	Infants n = 26	Perc. (%)	Toddlers n = 25	Perc. (%)	p-value
Previous injuries								
Head external injuries	No	40	78.4	21	80.8	19	76.0	0.679
	Any	11	21.6	5	19.2	6	24.0	
Body external injuries	No	33	64.7	20	76.9	13	52.0	0.063
	Yes	18	35.3	6	23.1	12	48.0	
Extracranial fractures	No	37	72.5	15	57.7	22	88.0	0.015
	Yes	14	27.5	11	42.3	3	12.0	
Head + body	No	25	49.0	12	46.2	13	52.0	0.676
	Any	26	51.0	14	53.8	12	48.0	
	head	0	0.0	0	0.0	0	0.0	
	body	15	29.4	9	34.6	6	24.0	
	both	11	21.6	5	19.2	6	24.0	
Extracranial injuries								
Neck external injuries	No	37	72.5	21	80.8	16	64.0	0.180
	Any	14	27.5	5	19.2	9	36.0	
Body external injuries	No	12	23.5	10	38.5	2	8.0	0.010
	Yes	39	76.5	16	61.5	23	92.0	
Intrathoracic injuries	No	38	74.5	21	80.8	17	68.0	0.296
	Any	13	25.5	5	19.2	8	32.0	
Intra-abdominal injuries	No	34	66.7	21	80.8	13	52.0	0.029
	Any	17	33.3	5	19.2	12	48.0	
Extracranial fractures	No	41	80.4	20	76.9	21	84.0	0.525
	Yes	10	19.6	6	23.1	4	16.0	
Cranial injuries								
Scalp external injuries	No	23	45.1	16	61.5	7	28.0	0.016
	Yes	28	54.9	10	38.5	18	72.0	
Face external injuries	No	20	39.2	15	57.7	5	20.0	0.006
	Any	31	60.8	11	42.3	20	80.0	
Subgaleal hemorrhages	No	15	29.4	12	46.2	3	12.0	0.007
	Yes	36	70.6	14	53.8	22	88.0	
Skull fractures	No	42	82.4	21	80.8	21	84.0	0.762
	Yes	9	17.6	5	19.2	4	16.0	
Suture diastasis	No	37	72.5	15	57.7	22	88.0	0.015
	Any	14	27.5	11	42.3	3	12.0	
EDH	No	41	80.4	20	76.9	21	84.0	0.525
	Yes	10	19.6	6	23.1	4	16.0	
Acute SDH	No	12	23.5	2	7.7	10	40.0	0.007
	Yes	39	76.5	24	92.3	15	60.0	
Older SDH	No	37	72.5	17	65.4	20	80.0	0.242
	Yes	14	27.5	9	34.6	5	20.0	
Overall SDH	No	9	17.6	2	7.7	7	28.0	0.057
	Any	42	82.4	24	92.3	18	72.0	
IDH	No	42	82.4	22	84.6	20	80.0	0.726
	Yes	9	17.6	4	15.4	5	20.0	
SAH	No	24	47.1	10	38.5	14	56.0	0.210
	Yes	27	52.9	16	61.5	11	44.0	
Intracerebral hemorrhage	No	43	84.3	22	84.6	21	84.0	0.952
	Yes	8	15.7	4	15.4	4	16.0	
Intracerebral necrosis	No	37	72.5	16	61.5	21	84.0	0.072
	Yes	14	27.5	10	38.5	4	16.0	
Global hypoxia–ischemia	No	32	62.7	15	57.7	17	68.0	0.447
	Any	19	37.3	11	42.3	8	32.0	
Intracerebral findings	No	19	37.3	8	30.8	11	44.0	0.329
	Any	32	62.7	18	69.2	14	56.0	
Brain involvement	No	34	66.7	17	65.4	17	68.0	0.843
	Any	17	33.3	9	34.6	8	32.0	
Cerebellum involvement	No	47	92.2	23	88.5	24	96.0	0.610
	Any	4	7.8	3	11.5	1	4.0	
Brainstem involvement	No	44	86.3	19	73.1	25	100.0	0.010
	Any	7	13.7	7	26.9	0	0.0	
Spinal cord injuries								
Cervical spinal cord injuries	No	38	74.5	17	65.4	21	84.0	0.127
	Any	13	25.5	9	34.6	4	16.0	
Cervical spinal cord EDH	No	49	96.1	25	96.2	24	96.0	1.000
	Any	2	3.9	1	3.8	1	4.0	
Cervical spinal cord SDH	No	44	86.3	19	73.1	25	100.0	0.010
	Any	7	13.7	7	26.9	0	0.0	
Cervical spinal cord SAH	No	48	94.1	26	100.0	22	88.0	0.110
	Any	3	5.9	0	0.0	3	12.0	
Cervical spinal cord Int hem	No	47	92.2	22	84.6	25	100.0	0.110
	Any	4	7.8	4	15.4	0	0.0	

TABLE 1—*Continued.*

Findings		All (n = 51)	Perc. (%)	Infants n = 26	Perc. (%)	Toddlers n = 25	Perc. (%)	p-value
Cervical spinal cord Necros.	No	48	94.1	23	88.5	25	100.0	0.235
	Any	3	5.9	3	11.5	0	0.0	
Thoracic spinal cord injuries	No	34	66.7	14	53.8	20	80.0	0.048
	Any	17	33.3	12	46.2	5	20.0	
L-S spinal cord injuries	No	37	72.5	16	61.5	21	84.0	0.072
	Any	14	27.5	10	38.5	4	16.0	
Ocular injuries								
Retinal hemorrhages	No	13	25.5	4	15.4	9	36.0	0.091
	Any	38	74.5	22	84.6	16	64.0	
Bilateral retinal hem.	No	15	29.4	5	19.2	10	40.0	0.132
	yes	36	70.6	21	80.8	15	60.0	
Macular fold	No	48	94.1	24	92.3	24	96.0	0.575
	Any	3	5.9	2	7.7	1	4.0	
Vitreous hemorrhage	No	42	82.4	20	76.9	22	88.0	0.465
	Any	9	17.6	6	23.1	3	12.0	
Bilateral vitreous hem.	No	43	84.3	21	80.8	22	88.0	0.703
	yes	8	15.7	5	19.2	3	12.0	
Optic nerve perineural SDH	No	14	27.5	4	15.4	10	40.0	0.049
	Any	37	72.5	22	84.6	15	60.0	
Bilateral optic nerve perineural SDH	No	20	39.2	8	30.8	12	48.0	0.258
	yes	31	60.8	18	69.2	13	52.0	

Perc., percentage; EDH, extradural hemorrhage; IDH, intradural hem.; SDH, subdural hem.; SAH, subarachnoid hem; L-S, lumbosacral.

the most commonly involved area of the spinal cord (33.3%, n = 17). followed by the lumbosacral area (27.5%, n = 14), and the cervical area (15.5%, n = 13). Regarding the cervical spinal cord, we found two cases of EDH, seven of SDH, three of SAH, four of intraparenchymal hemorrhage, and three of necrosis. The dorsal nerve roots were not dissected.

Ocular Pathology—Retinal hemorrhages and perineural optic nerve SDH were a very common finding: 74.5% of subjects (n = 38) showed retinal hemorrhages, of which 36 were bilateral, 72.5% (n = 37) showed perineural optic nerve SDH, of which 31 were bilateral. The eyes of one subject were examined at the hospital antemortem and showed unspecified bilateral retinal hemorrhages. Regarding the remaining subjects who underwent a postmortem ocular examination by an ophthalmologist, we did not find any focal retinal hemorrhages—in each example the hemorrhages were extensive (scattered or widespread). In all but three cases, there was involvement of the entire retina, including the ora serrata. Of the three cases without involvement of the entire retina, one had bilateral involvement of the central part (posterior pole) of the retina, and two had unilateral involvement of the central retina. All the cases of retinal hemorrhages involved the intraretinal layer: In 15 cases, only the intraretinal layer was involved, while in 18 cases the intraretinal layer together with the subretinal layer was involved, and in five cases the intraretinal layer together with the preretinal layer was involved. There was a significant association between intracranial subdural bleeding and the presence of retinal hemorrhage and between intracranial subdural bleeding and optic nerve SDH. Vitreous hemorrhages were present in 17.6% of cases (n = 9), and in eight cases, they were bilateral. Macular folds were an uncommon finding being present in only 5.9% (n = 3).

Survival Intervals—We analyzed the survival intervals in victims who survived the initial injury (66.67%, n = 34) and found that they ranged from about an hour to more than 2 years. Specifically, one subject survived about a hour, 15 subjects <1 day, 13 subjects between 2 and 7 days, three subjects between 2 and 4 weeks, one subject more than a month, and one subject more than 2 years. The majority of child abuse victims (n = 29) did not survive more than 1 week after the fatal injury.

In 15 of the 34 cases with a survival interval of an hour or more, medical records reported that an intubation was made, while in one case a prolonged ventilation was performed. In four cases, cardiopulmonary resuscitation (CPR) was attempted.

Patterns of Injury in Different Age Groups

Previous Injuries—Fourteen of the 26 infants and 12 of the 25 toddlers had previous traumatic injuries. The frequency of older extracranial fractures was significantly higher in infants than toddlers (42% vs. 12%, p = 0.015), while signs of previous cutaneous and subcutaneous injuries (to the head and to the body) were more common in toddlers. No healed skull fractures were detected (Fig. 1).

Extracranial Findings—The frequency of cutaneous and subcutaneous injuries (defined as bruises. lacerations. and abrasions on the body with the exception of the head) was significantly higher in toddlers: 92% vs. 62% (p = 0.01). Neck cutaneous and muscular injuries seemed to be more common in toddlers than in infants. Abdominal blunt force injuries were significantly more common in toddlers (48% vs. 19%, p = 0.029). There was a suggestion that toddlers were more likely to have intrathoracic injury and less likely to present with extracranial fractures (Fig. 2).

Head and Spine Findings—Head external signs (bruises, abrasions, or lacerations) were more frequent in toddlers than in infants (72% vs. 38%, p = 0.016). Also, SGH were significantly more common in toddlers (88% vs. 54%, p = 0.007). The frequencies of diastases of the cranial sutures and acute SDH were significantly higher in infants (42% vs. 12%, p = 0.015 and 92% vs. 60%, p = 0.007, respectively). The brainstem was injured only in infants (27% vs. 0%, p = 0.01). There was a suggestion that infants were more likely to have skull fractures. EDH, SDH, SAH, global hypoxia–ischemia, intracerebral

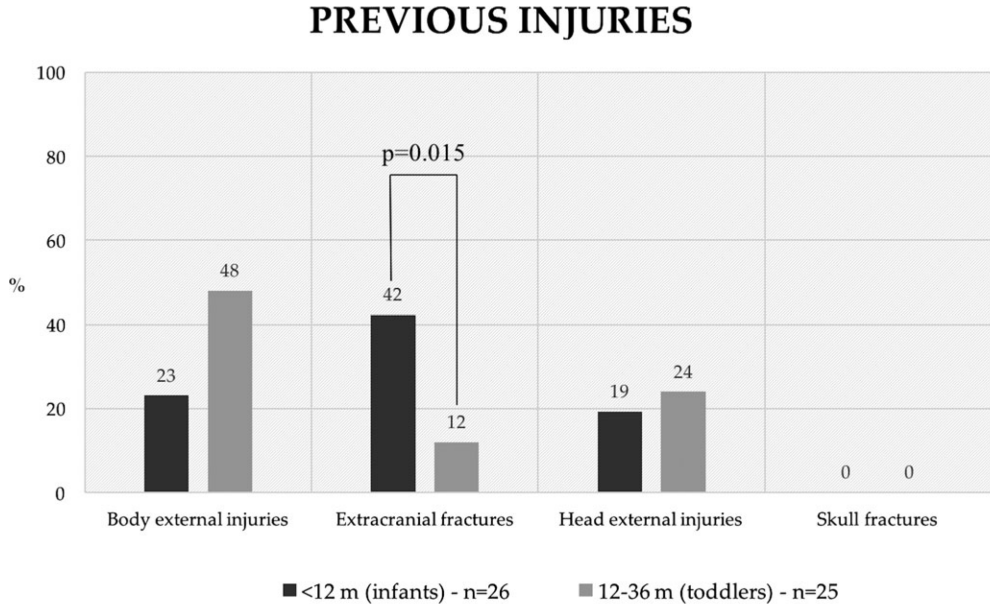

FIG. 1—*Comparison of the patterns of previous injuries in infants and toddlers.* p-*values are shown only when <0.05.*

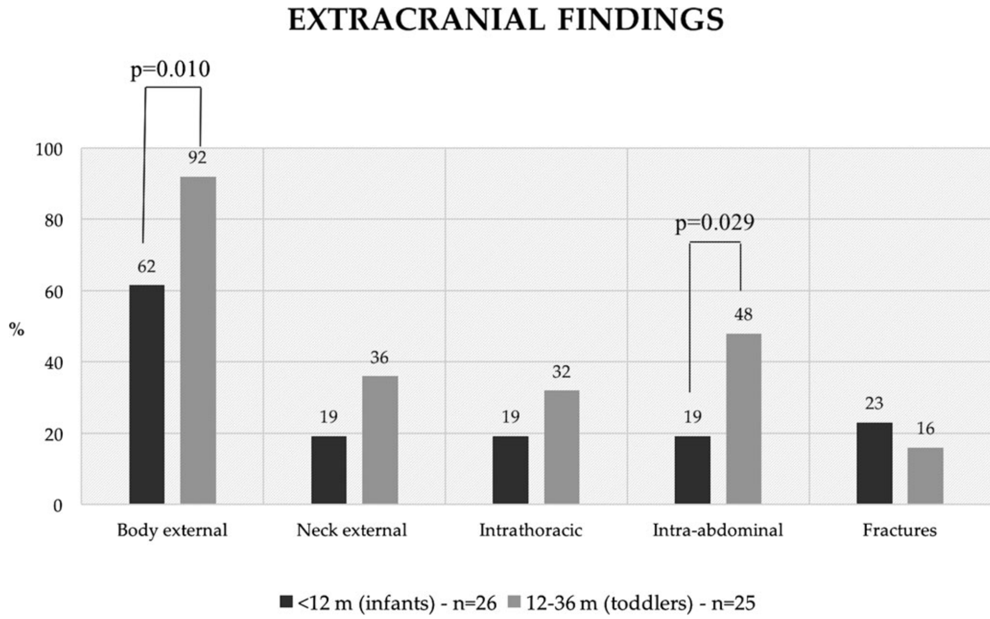

FIG. 2—*Comparison of the patterns of extracranial findings in infants and toddlers.* p-*values are shown only when <0.05.*

necrosis and an involvement of brain and cerebellum, but less likely to have IDH (Fig. 3*a,b*).

Spinal cord findings were more common in infants. We found a statistical significance regarding the thoracic spinal cord involvement that was observed more commonly in infants (46% vs. 20%, p = 0.048).

Ocular Findings—No statistically significant differences between the age groups were seen regarding ocular findings, even if they appeared to be more common in infants (Fig. 4).

Impact to the Head—We define "signs of impact to the head" to mean any indication of impact to the head ranging from the most subtle bruise or abrasion or laceration of the skin of the scalp or the face, to a SGH or a skull fracture. We did not observe statistically significant differences between the pathological findings of the 42 subjects (82.4%) with signs of impact and the nine subjects (17.6%) with no signs of impact. Table 2 shows the intracranial, spinal, and ocular features of the sample, comparing findings in subjects with no sign of impact with those showing sign of impact.

Intracranial and Spinal Findings—Of the nine subjects who showed no signs of impact to the head, none had EDH; two had IDH; seven had acute SDH, always described as a thin film of blood (thus, no mass lesion); three had SAH; six intracerebral findings (mostly intracerebral necrosis); and two had involvement of cervical spinal cord (Fig. 5).

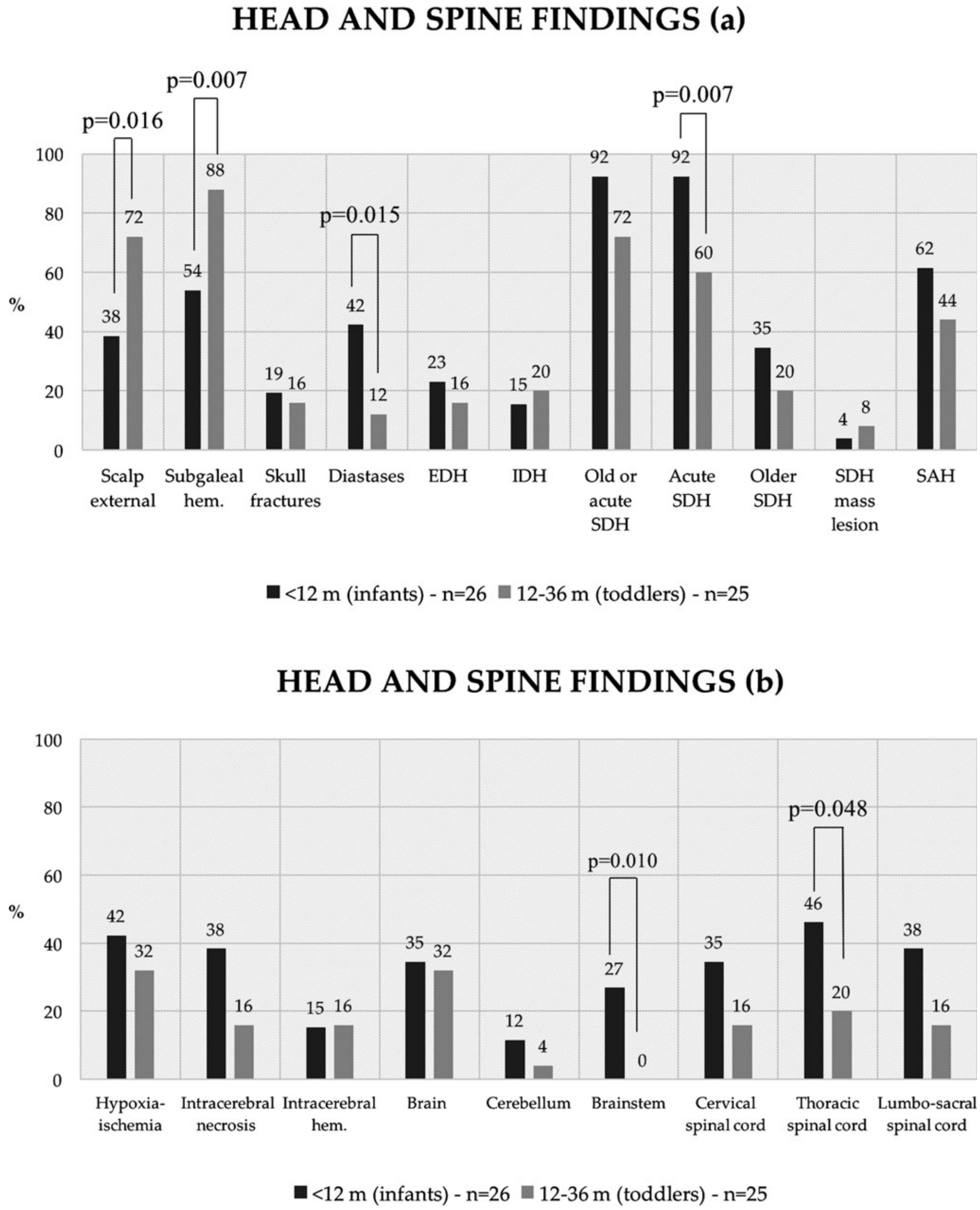

FIG. 3—*(a,b) Comparison of the patterns of head and spine injuries in infants and toddlers.* p*-values are shown only when <0.05.*

Ocular Findings—Among the subjects of the "nonimpact" group, eight cases had bilateral retinal hemorrhages, three vitreous hemorrhages (of these, two were bilateral), and seven had bilateral optic nerve SDH (Fig. 6).

Comparable Accidental Deaths

A total of 111 child accidental deaths were found in the database over this same period. Of these, 24 deaths were due to severe trauma (e.g., motor vehicle collisions, vehicles striking pedestrians, heavy falling objects such as televisions, falls). Two cases of death due to a fall from a height showed patterns of injuries that were similar to the patterns of injury in cases determined to be deaths due to child abuse.

The first case involved a 2-year-old subject who fell from a bunk bed (1.5 m). The subject fell backwards and he first struck the back of his head on one of the bunk bed legs and then his forehead on the wall close to the floor. He sustained abrasions to the face and back, left parietal and occipital bone fractures, frontal, parietal, and occipital SGH, contusions to the left and right frontal lobes, posterior SAH, intraretinal and subretinal hemorrhages. The investigation disclosed no evidence of abuse.

The second case involved a 7-month-old subject who fell from the arms of his mother while she was walking down the stairs. The subject fell backwards and landed on the bottom first carpeted stair and then rolled off the stair onto the floor. He sustained left parietal and left sided frontal bone fractures, diffuse SAH and SDH, and cerebral edema.

Discussion

Our retrospective review of the cases of deaths due to physical abuse of subjects <3 years old was focused on gaining a better understanding of the patterns of injury that can occur at younger

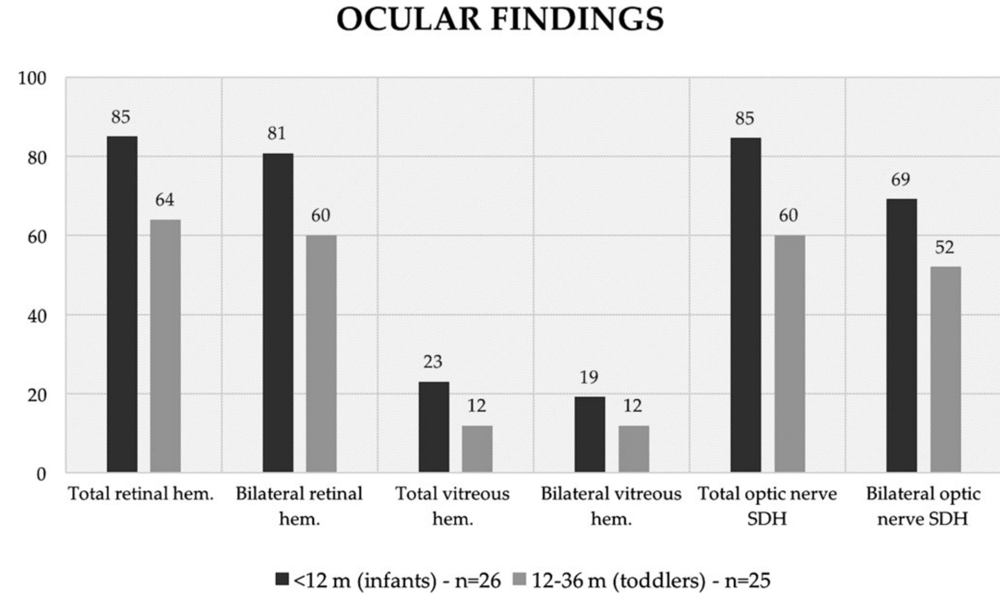

FIG. 4—*Comparison of the patterns of ocular findings in infants and toddlers.* p-*values are shown only when <0.05.*

ages (with special regard to the differences between infants and toddlers), as well as emphasizing the importance of certain special procedures in suspected cases of child abuse. Secondarily, we wished to compare the injuries seen in cases of abuse with types of trauma encountered in childhood accidental fatalities. We found only two cases of accidental deaths with pathological findings comparable to those found in the child abuse deaths. Each case was due to a fall from a short height and will be described later.

A noteworthy finding in our study was the larger number of victims among infants 0–12 months (26 cases), vs. toddlers 12–36 months (25 cases). Moreover, in the latter group, 17 cases involved toddlers 12–24 months, while only eight cases involved toddlers 24–36, These findings are in agreement with some researchers who have also found that homicides due to child abuse are more frequent in the early months of life (10,11).

Our results agree with other researchers who have found that head injuries are the leading cause of death in physical child abuse (12–15). The prevalence of head injuries in contrast to trunk and limb injuries in infants seems to be due to the larger size of the head compared with the rest of the body making the skulls and brains of infants more vulnerable to injuries than those of older children (16). In our series, eight of the nine cases of deaths due solely to extracranial injuries occurred in subjects more than 12 months old.

External injuries to the head and SGH were present both in subjects who died of head trauma and in subjects whose deaths were due to other causes. They were more common in subjects older than 12 months.

Skull fractures were present in nine children in our series. As shown more clearly in our Results section, the skull fractures in our study population were mostly linear. single, unilateral, localized on the parietal bones, and extended across suture lines to involve multiple bones of the skull. All of our cases with skull fractures also involved intracranial injuries. According to the literature, skull fractures of the parietal bone, followed by the occipital, frontal, and temporal bones are the most commonly encountered injuries in both physical abuse and accidental injuries, Madea et al. (16) considered that depressed fractures are likely to have been caused by high force impact (physical abuse). Also, Flaherty et al. (17) suggested that complex or bilateral skull fractures are typical of nonaccidental trauma. Other authors found that in both circumstances (abuse vs. accident) the most common feature is a simple, unilateral, linear fracture of the parietal bone without depression (18). Moreover, subjects <1-year-old are six times more likely to sustain a skull fracture than older children, and the fractures are often the result of child abuse, even if accidental falls cannot be dismissed. In the same way, Hobbs (19) stated that about 33% of skull fractures in children <2 years old result from child abuse. About 7–30% of the fractures observed in child abuses are skull fractures (20), being observed in about 40% of children whose deaths were due to abuse (21). Finally, in their systematic review, Piteau et al. (22) found that skull fracture(s) plus intracranial injury, as noted in our cases, were associated with abusive head trauma, while isolated skull fractures were associated with nonabusive head trauma.

A differential diagnosis that includes nonaccidental as well as accidental causes of skull fractures in child deaths is always required in forensic practice. Accidental deaths due to severe trauma (i.e., motor vehicle collisions, vehicles striking pedestrian, skull fractures from heavy falling objects) usually result in extensive multiple injuries together with skull fractures and intracranial findings. In accidental cases such as these, the investigative history usually corroborates the manner of death, since it corresponds with the injuries found, and excludes child abuse. Conversely, a fall from a short height (either unwitnessed or witnessed by a single caretaker) can result in skull fractures in children with a very similar pattern to the ones found in inflicted trauma. Confounding this diagnostic dilemma, the majority of head injuries in child abuse and accidental head trauma are often both explained by parents as accidental. According to the literature (23,24), accidental skull fractures will rarely lead to serious or life-threatening intracranial injury. Further, skull fractures due to accidental falls are rarely seen in concert with simultaneous fractures in other skeleton segments (i.e., ribs or extremities). The investigative history is a fundamental part of the diagnostic process, as an accidental skull fracture can nearly always be

TABLE 2—*Intracranial, spinal, and ocular features of the sample, comparing findings in subjects with no sign of impact with those showing no sign of impact.*

		No (9)		Yes (42)		
		N	Percentage (%)	*N*	Percentage (%)	*p*-value
EDH	No	9	100.0	32	76.2	0.176
	Yes	0	0.0	10	23.8	
IDH	No	7	77.8	35	83.3	0.651
	Yes	2	22.2	7	16.7	
Acute SDH	No	2	22.2	10	23.8	0.919
	Yes	7	77.8	32	76.2	
Older SDH	No	4	44.4	33	78.6	0.037
	Yes	5	55.6	9	21.4	
Overall SDH	No	0	0.0	9	21.4	0.126
	Any	9	100.0	33	78.6	
SAH	No	6	66.7	18	42.9	0.194
	Yes	3	33.3	24	57.1	
Intracerebral hemorrhage	No	9	100.0	34	81.0	0.322
	Yes	0	0.0	8	19.0	
Intracerebral necrosis	No	5	55.6	32	76.2	0.236
	Yes	4	44.4	10	23.8	
Global hypoxia–ischemia	No	6	66.7	26	61.9	1.000
	Yes	3	33.3	16	38.1	
Intracerebral findings	No	3	33.3	16	38.1	0.789
	Any	6	66.7	26	61.9	
Suture diastasis	No	5	55.6	32	76.2	0.236
	Yes	4	44.4	10	23.8	
Brain	No	5	55.6	29	69.0	0.459
	Any	4	44.4	13	31.0	
Cerebellum	No	7	77.8	40	95.2	0.139
	Any	2	22.2	2	4.8	
Brainstem	No	8	88.9	36	85.7	1.000
	Any	1	11.1	6	14.3	
Cervical spinal cord injuries	No	7	77.8	31	73.8	1.000
	Any	2	22.2	11	26.2	
Thoracic spinal cord injuries	No	6	66.7	28	66.7	1.000
	Any	3	33.3	14	33.3	
Lumbosacral spinal cord injuries	No	6	66.7	31	73.8	0.692
	Any	3	33.3	11	26.2	
Bilateral retinal hemorrhage	No	1	11.1	14	33.3	0.251
	Yes	8	88.9	28	66.7	
Bilateral optic nerve hemorrhage	No	2	22.2	18	42.9	0.454
	Yes	7	77.8	24	57.1	
Bilateral vitreous hemorrhage	No	7	77.8	36	85.7	0.620
	Yes	2	22.2	6	14.3	

EDH, extradural hemorrhage; IDH, intradural hem.; SDH, subdural hem.; SAH, subarachnoid hem.

clearly explained with a thorough investigation; the autopsy and radiologic findings cannot be adequately interpreted in a vacuum.

Accidental falls from a short-distance (23)—up to 1.5 m—(bed, chair, coach, arms of parents) rarely result in severe or life-threatening injuries such as intracranial hemorrhages or other intracranial injuries. When intracranial injuries are present, brain involvement is almost always focal. That being said, fatalities from short falls are extremely rare but do occur: 0.14–0.22 deaths per 100000 children between aged from 0 to 4 years (25). In accidental falls downstairs, multiple injuries are usually present on the head, neck and distal extremities and occasional severe brain injuries that sometimes result in death. Due to the multiple injuries that can be found in these victims, falling from the stairs can be comparable to a fall into a "hole full of sharp rocks on the base." Our fatal case of an accidental fall downstairs showed a severe pattern of intracranial injuries. Falling from a bunk bed usually result in multiple injuries to different regions of the body, but intracranial injuries are routinely absent. Of course, no rule of thumb applies in all cases. In our fatal case due to an accidental fall from a bunk bed, the subject sustained a severe double trauma due to a high velocity head impact against two different hard surfaces (leg of the bed and wall).

Diastases of cranial sutures were more common than skull fractures and could be either a direct consequence of trauma or due to raised intracranial pressure from any cause, because suture diastases occurred both in cases with signs of impact to the head as well as no signs of impact. Their frequency was significantly higher in infants than in toddlers, as expected, because of the progressive fusion of the sutures during growth.

Extradural hemorrhages is rarely seen in pediatric cases due to the tight adherence of the dura to the skull and because of the elasticity of the young skull. In fact, in our series, EDH was rare (10 cases) and not always associated with skull fractures. EDH did not occur in subjects with no signs of an impact. EDHs are typically associated with accidental trauma but have been also described in abused children. EDH may occur with relatively minor trauma to the parietal or temporal skull if the vulnerable middle meningeal artery is torn, so it is frequently observed in accidental trauma (26,27).

Intradural hemorrhages is caused by physical or physiologic damage to the dural capillary plexus that, according to some researchers (28,29), can lead to SDH. In our series, IDH was present in nine cases, all with concomitant subdural bleeding (eight with acute SDH and one with an older SDH). Two cases occurred in subjects with no signs of an impact to the head.

In our series, SDH was the most common intracranial finding, being present in 42 cases. SDH was observed both in the subjects with and in those without visible evidence of impact injury. The frequency of acute SDH (39 cases) was significantly higher in infants and these bleedings were mostly bilateral and hemispheric. Infants are more affected by subdural hematoma than toddlers and older children, because the brain of infants has more space than the brain of older children to move around in the skull upon impact (30). It has been reported in the literature that subdural hemorrhages in cases of abusive pediatric head trauma are rarely massive (31). Our study population corroborates this finding to the extent that SDH was usually found in the form of a thin film of blood; we identified only three cases in which SDH acted as a space-occupying lesion, all following impacts to the head. This seems to confirm that SDH is not typically a lesion producing increased intracranial pressure, but rather a marker of brain movement within the cranial cavity, which may be associated with some shearing brain injury (e.g., diffuse axonal injury) (32). In fact, because the dura is firmly attached to the skull and the arachnoid to the cerebral cortex, most brain motion occurs across the potential subdural space. The thin-walled bridging veins are thus easily vulnerable to tearing (24). Therefore. in every pediatric autopsy it is extremely important for the pathologist to remove the brain personally or directly observe its removal when performed by a technician. Otherwise, a thin layer of blood from subdural bleeding could easily be missed as it will tend to slide quickly off the surface of the brain as the calvarium is removed.

Subdural hemorrhages caused by accidental trauma are typically produced by severe force such as a motor vehicle accident, ejection from a motor vehicle, or a fall from a significant height. Accidental SDHs usually occur at the site of impact, are limited to the cerebral convexities, and are often isolated and associated with an overlying fracture (26).

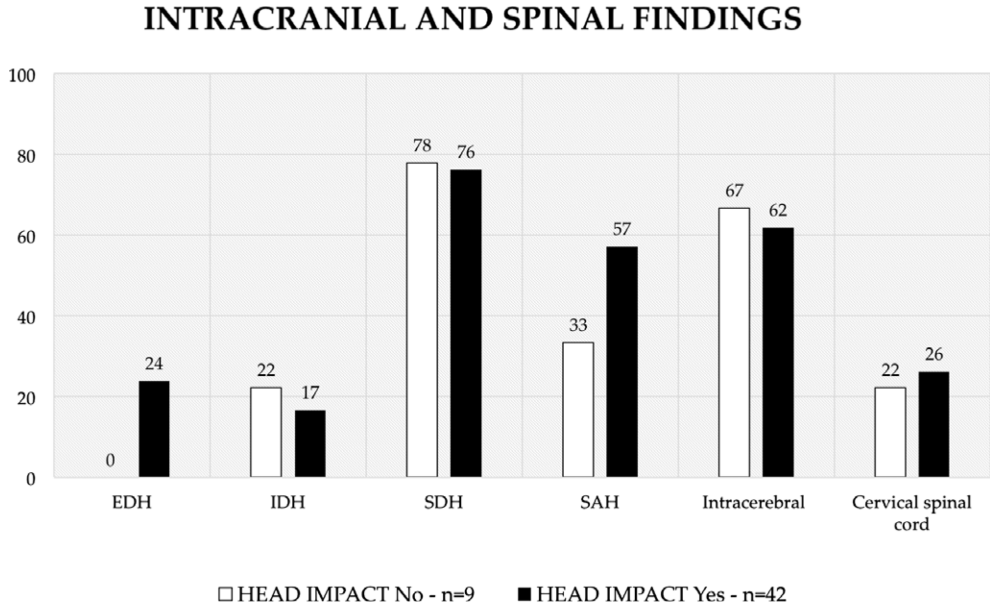

FIG. 5—*Comparison of intracranial and spinal findings in subjects with no sign of impact with those showing signs of impact.* p-*values are shown only when <0.05.*

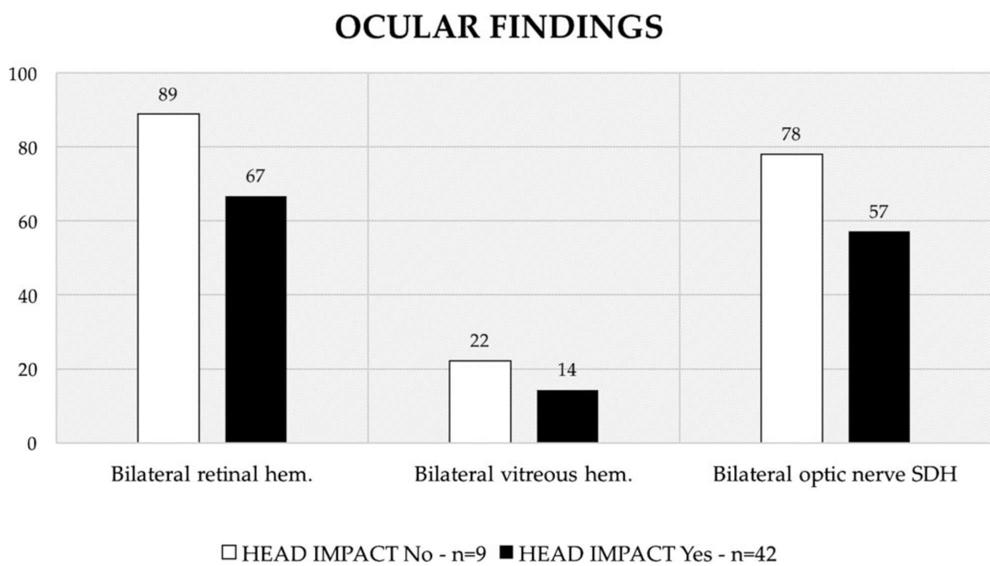

FIG. 6—*Comparison of ocular findings in subjects with no sign of impact with those showing signs of impact.* p-*values are shown only when <0.05.*

Subarachnoid hemorrhages were present in about half the cases, all hemispheric and mostly bilateral. They were observed near fracture sites or together with SDHs. This occurs because the bridging veins are surrounded by an arachnoid sheath, and tears of bridging veins usually produce both SDH and SAH (14). SAHs may occur spontaneously or as a result a severe accidental trauma. SAH unaccompanied by SDH or other features suggestive of trauma is most likely a consequence of natural disease. In our cases. the coexistence of SDH and SAH simultaneously was suggestive of abuse. SAH was observed both in cases with signs of impact to the head and in cases with no evidence of impact.

Gross inspection showed that the majority of brains had edema. The most frequent microscopic finding was global hypoxia–ischemia, followed by focal necrosis, and hemorrhages. All these findings with the exception of hemorrhages were observed both in cases with signs of impact and in cases with no signs of impact. Regarding cerebral edema and global hypoxia–ischemia, in one of our cases the subject was placed on a ventilator and in 15 cases an endotracheal intubation was performed. The possibility of ventilation must obviously be taken into account when trying to identify the cause of brain edema. In each of our cases, the medical records clearly indicated that brain edema and hypoxic changes were observed on arrival at the hospitals. According to some authors, the high incidence of intubation for respiratory insufficiency in children with abusive head trauma strongly suggests that they were exposed to previous periods of hypoxemia (33).

In our population, no diffuse axonal injury (DAI) was detected, although some authors consider it to be a frequent finding in child abuse (14,34,35). β-APP immunohistochemistry was not routinely performed in the Office during the period selected for this study. Nevertheless. our results seem to be similar to the experience of Geddes et al. (31,36). who consider DAI a rarity in nonaccidental injury.

Regarding the localization of intracranial injuries, the most commonly affected site was the brain, followed by the brainstem, and the cerebellum. In our series, the brainstem was involved only in infants. Hemorrhages and necrosis were the most common findings in this area. The brainstem was involved in subjects with signs of impact and those with no signs of impact: It was involved in six cases with signs of impact to the head and in one case with no signs of impact (here a SDH was found). These findings support a conclusion that brainstem damage can be either primary (when due to fractures or countercoup mechanism after an impact) or secondary (when caused by elevated intracranial pressure) (37).

When considering the distribution of spinal cord damage—EDH, SDH, SAH as well as microscopic evidence of internal injury (hemorrhage and necrosis)—our data showed that the thoracic spinal cord was the most frequently involved area of the spinal cord. Moreover, the frequency of thoracic spinal cord injuries was significantly higher in infants in comparison with toddlers. This finding was not expected because the axis of maximum flexion is higher in the infant cervical spine than in adults, so that usually infant injuries tend to affect the higher levels of the cord (38–40). When considering only hemorrhagic and necrotic injuries, in our series. the most frequently involved area was the cervical spine, as expected. Moreover. we noted that cervical spinal cord injury was more common in infants, even if no statistically significant differences were observed. For these reasons, the entire spinal cord should be carefully removed with preservation of the nerve roots and microscopic examination should be done of any grossly suspicious sites.

Regarding vertebral injuries, it is recognized that the cervical region of infants is the most mobile portion of the spine due to the horizontally oriented facets, lax ligaments, weak cervical muscles, and a large head. This can result in cervical ligament and cord damage instead of skeletal injury. Inflicted spine injuries are usually more common at the thoraco-lumbar junction than in the cervical region (38,39). In our case series, we could not find any vertebral fracture or dislocation.

All the eyes in our subjects—except those of the subject whose retinal hemorrhages were visualized in hospital—were examined by an ophthalmologist: Retinal and optic nerve perineural SDH was a very common finding (74.5% and 72.5%. respectively), in accordance with the literature (28,29,41–43). Most were bilateral. The locations of the retinal hemorrhages included the posterior pole, retinal periphery, and ora serrata (in the majority of cases involving the entire retina). The hemorrhages were described as scattered or widespread, and no focal hemorrhages were reported. The hemorrhages always consisted of intraretinal hemorrhages ranging from mild retinal hemorrhages (exclusively intraretinal, 15 cases) to moderate or severe (multilayered—intraretinal, preretinal, and subretinal, 23 cases). As other researchers (44–46) have found, in cases of nerve sheath involvement, hemorrhages preponderantly affected the subdural space. Vitreous hemorrhages and macular folds were present as well, even if rare. No statistically significant difference between age groups was seen, although ocular findings appeared to be more common in infants. This finding could be explained by the particularly strong adherence between the vitreous and posterior pole and peripheral retina in infants and toddlers. Therefore, traumatic events may produce shearing forces that allow the vitreous to pull on the retina causing disruption of retinal vessel autoregulation. Moreover, there is another hypothesis that links increased intracranial pressure to retinal hemorrhage: Pressure transmitted along the optic nerve sheath results in compression of the central retinal vein which leads to vascular ruptures (47).

Hemorrhages and retinal folds were seen both in cases with evidence of impact occurrence and in cases with no evidence of impact. No intra-ocular bleeding was observed in the cases of subjects who died due to extracranial injuries. There was a significant association between intracranial subdural bleeding and the presence of retinal hemorrhages and between intracranial subdural bleeding and optic nerve SDH, as reported also by several authors (31,34,48). We found eight cases of periocular ecchymosis (three bilateral and five unilateral): All except two of these (both unilateral) were associated with intra-ocular bleeding, but there was no association between the laterality of periocular injury and the pattern of ocular involvement.

Eye involvement is considered a significant finding in child abuse. According to the literature (49,50). the forces required to generate retinal bleeding need to be considerable and can almost never be achieved during ordinary domestic accidents. Therefore, accidental injuries seem to be insufficient to cause retinal bleeding, except the most severe (i.e., motor vehicle accidents or falling from extreme heights). No ocular findings can be considered pathognomonic for child abuse, but the Royal College of Ophthalmologists Working Party (51) stressed that: “No absolute values can be given for the angular acceleration forces required to produce retinal bleeding or other injury, but there is good evidence that they must be considerable.”

Finally, less emphasis should be given to cardiopulmonary resuscitation (CPR) as a cause of ocular bleeding because only isolated reports suggest that CPR can cause retinal hemorrhages. According to the literature, ocular pathology due to CPR seems to be extremely rare (52–55). When a retinal hemorrhage is detected in a child who underwent CPR, prior trauma should be assumed until proven otherwise (56,57). In our series. we found only four subjects who underwent CPR. Although ocular hemorrhages were also found in these four cases, the far larger number of cases in our series with ocular hemorrhages in the absence of prior CPR (34 cases) preclude any generalization regarding an association between CPR and ocular hemorrhages.

Given the importance of documenting intra-ocular hemorrhage in cases of suspected abuse in infants and young children, the eyes with a portion of each optic nerve should be removed and submitted for examination. We suggest removing the eyes using the posterior approach through the anterior cranial base to avoid the risk of damage to ocular structures, in particular the optic nerve. Also, if the child survived in hospital for an interval of time, any hospital records documenting premortem ophthalmic examinations should be included.

In our series, evidence of extracranial injuries (thoracic or abdominal internal injuries or extracranial fractures) was observed in 23 cases. Among these, abdominal injuries were significantly more common in toddlers, as previously reported by other authors (58). This finding could theoretically be explained by the progressive increases in size of the abdomen during child development, making this area of the body more vulnerable to injury than those of younger children. Recent extracranial fractures occurred in 10 subjects and mostly involved multiple rib fractures, a finding commonly believed to be highly suspicious for child abuse (17,59). We also found several patterns of fractures that are considered to have a high specificity for abuse (60): recent and old fractures in the same subject, two “bucket handle” fractures in the tibia, and a clavicle fracture. In particular, previous extracranial fractures suggesting abuse were significantly more common in infants. This suggests that in this age group, in many cases, a fatal abusive episode is the culmination of previous episodes of nonlethal abuse. While evidence of cutaneous and subcutaneous injuries (bruises, abrasions or lacerations) to the body alone cannot be considered suggestive of an abusive head trauma, the presence of multiple affected body districts, together with recent or old fractures, should increase the suspect of an abuse. Therefore, we recommend a detailed radiographic survey in all cases of suspected child abuse of at least the most frequently affected body sites (ribs and limbs). Any fractures that are identified should, whenever possible, be dated.

In an extensive pooled analysis, Maguire et al. (61) concluded that the probability of an abusive head trauma in children younger than 3 years old depends on the number and the type of specific clinical features. In particular, they stated that in the presence of an intracranial injury and one or two specific clinical features, with retinal hemorrhages and rib fractured being the most discriminating, an abusive head trauma can be taken into account. In the presence of three or more specific clinical findings, the diagnosis of abusive head trauma is strongly suggested. Our results are consistent with those observed by these authors. In our analyses, the extracranial fractures most commonly involved the ribs and the retinal hemorrhages were observed in a high percentage of cases, confirming them as important pathological features that are strongly related to abusive head injuries. Regarding the extracranial physical findings, the authors considered rib and long-bone fractures and head and/or neck bruising, emphasizing that most of these injuries can be present in children that do not have an abusive head trauma, while their combination with an intracranial injury slightly increases the probability of an abusive head trauma.

In conclusion, we found several statistically significant differences between age groups, some of which can be explained by the anatomical and physiological features that distinguish infants from toddlers. The frequencies of diastases of the sutures, acute SDHs, brainstem injuries, thoracic spinal cord damage, and previous extracranial fractures were significantly higher in infants than in toddlers. An interesting finding was that the brainstem injuries were observed only in infants. An unexpected finding was the higher frequency of the thoracic spinal cord involvement in infants, as usually in younger children the more cranial levels of the cord tend to be affected. We also found that ocular findings were more common in infants, although no statistically significant difference was observed between the groups.

On the other hand, the frequency of cutaneous and subcutaneous injuries to the head and to the body, the frequency of SGHs, and the frequency of abdominal blunt force injuries were higher in toddlers than in infants.

We did not find any differences between the pathological findings observed in the subjects with signs of impact to the head and those with no evidence of an impact. While the signs of head impact should encourage the pathologist to search for intracranial injury, one should remember that intracranial injuries can occur with subtle or no impact signs at all.

Our results are consistent with the literature (61,62) regarding the association of multiple injuries (skull fractures, intracranial hemorrhages, retinal hemorrhages, old and recent extracranial fractures, skin injuries) and deliberately inflicted injury. Our findings do not support the presence of multiple skull fractures, bilaterally located fractures, and fractures that cross-sutures as being reliable markers of abuse because in the majority of our cases only a single, linear, unilateral fracture of the skull was observed. The findings, however, of simultaneously intracranial pathologies underlying skull fractures strongly suggest abuse because in accidentally inflicted injuries intracranial findings are usually not present.

Our study was not without limitations. The small size of our sample population prevented us from obtaining a more accurate subgroup analysis. The lack of a significant control group (only two cases of accidental death were found) did not allow us to perform a proper comparison between homicidal and accidental cases. Beta-APP staining was not routinely performed in the Office during the years from which our cases were drawn, so we were unable to determine the presence or absence of DAI.

In every case of suspected child abuse, a multidisciplinary approach is required for the forensic pathologist to reach a correct diagnosis (63). The findings from the postmortem examination, and histopathological, neuropathological, ophthalmological, and radiological information should be evaluated, together with accurate investigative reports and medical history. In cases in which there is intracranial injury, but no evidence of impact injury to the head and/or extracranial pathology, caution must be used before certifying the manner of death as a “homicide.” It is necessary to keep an open mind to all reasonable possibilities recognizing that both trauma and natural disease are often in the differential diagnoses. In some cases, an “undetermined” manner of death should be considered.

References

1. U.S. Department of Health and Human Services: Children’s Bureau. Child abuse prevention and treatment act as amended by P.L. 111–320, the CAPTA Reauthorization Act of 2010; http://www.acf.hhs.gov/sites/default/files/cb/capta2010.pdf (accessed June 2, 2014).
2. U.S. Department of Health and Human Services: Administration for Children & Families. Child maltreatment, 2013; http://www.acf.hhs.gov/programs/cb/resource/child-maltreatment-2013 (accessed June 2, 2014).
3. Gill JR, Andrew T, Gilliland MGF, Love J, Matshes E, Reichar RR. National Association of Medical Examiners Position Paper: recommendations for the postmortem assessment of suspected head trauma in infants and young children. Acad Foren Pathol J 2014;4(2):206–13.
4. Gilbert-Barness E, Debich-Spicer DE. Handbook of pediatric autopsy pathology, 1st edn. Totowa, NJ: Humana Press. 2005.
5. Judkins AR, Hood IG, Mirchandani HG, Rorke LB. Technical communication: rationale and technique for examination of nervous system in suspected infant victims of abuse. Am J Forensic Med Pathol 2004;25 (1):29–32.
6. Sheaff MT, Hopster DJ. Fetal, perinatal, and infant autopsies. In: Sheaff MT, Hopster DJ, editors. Post mortem technique handbook, 2nd edn. London, U.K.: Springer. 2005;350–419.
7. Spitz WU. Investigation of deaths in childhood. In: Spitz WU, editor. Spitz and Fisher’s medicolegal investigation of death. Guidelines for the application of pathology to crime investigation, 4th edn. Springfield, IL: Charles C. Thomas Publisher, LTD, 2006;343–435.
8. Walters BL. Handbook of autopsy practice, 4th edn. Totowa, NJ: Humana Press, 2009.
9. Dettmeyer R. Pregnancy-related death, death in newborns, and sudden infant death syndrome. In: Dettmeyer R, editor, Forensic histopathology: fundamentals and perspectives, 1st edn. Berlin, Germany: Springer, 2011;347–80.
10. DiScala C, Sege R, Li G, Reece RM. Child abuse and unintentional injuries: a 10-year retrospective. Arch Pediatr Adolesc Med 2000;154(1):16–22.
11. Agran PF, Anderson C, Winn D, Trent R, Walton-Haynes L, Thayer S. Rates of pediatric injuries by 3-month intervals for children 0 to 3 years of age. Pediatrics 2003;111(6 Pt 1):e683–92.
12. Jenny C, Isaac R. The relation between child death and child maltreatment. Arch Dis Child 2006;91(3):265–9.
13. Graupman P, Winston KR. Nonaccidental head trauma as a cause of childhood death. J Neurosurg 2006;104(4 Suppl):245S–50S.
14. Case ME. Abusive head injuries in infants and young children. Leg Med (Tokyo) 2007;9(2):83–7.
15. Love JC, Derrick SM, Wiersema JM. Skull Fractures. In: Love JC, Derrick SM, Wiersema JM, editors. Skeletal atlas of child abuse, New York, NY: Humana Press, 2011;9–37.

16. Minns RA, Madea B, Kernbach-Wighton G. Non-sexual abuse in children. In: Madea B, editor. Handbook of forensic medicine. Chichester, U.K.: Wiley Blackwell. 2014;681–701.
17. Flaherty EG, Perez-Rossello JM, Levine MA, Hennrikus WL. American Academy of Pediatrics Committee on Child Abuse and Neglect, Section on Radiology, American Academy of Pediatrics, Section on Endocrinology, American Academy of Pediatrics, Section on Orthopaedics, American Academy of Pediatrics, Society for Pediatric Radiology, Evaluating children with fractures for child physical abuse. Pediatrics 2014;133(2):e477–89.
18. Hymel KP, Spivack BS. The biomechanics of physical injury. In: Reece RM, Ludwig S, editors, Child abuse – medical diagnosis and management, 2nd edn. Philadelphia, PA: Lippincott Williams & Wilkins. 2001;1–22.
19. Hobbs CJ, Hanks HGI, Wynne JM. Child abuse and neglect – a clinician's handbook. London, U.K.: Churchill Livingstone. 1999.
20. Kleinman PK, Barnes PD. Head trauma. In: Kleinman PK, editor. Diagnostic imaging of child abuse, 2nd edn. St. Louis, MO: Mosby. 1998;285–342.
21. Kleinman PK, Marks SC Jr, Richmond JM, Blackbourne BD. Inflicted skeletal injury: a postmortem-radiologic-histopathologic study in 31 infants. Am J Roentgenol 1995;165(3):647–50.
22. Piteau SJ, Ward MG, Barrowman NJ, Plint AC. Clinical and radiographic characteristics associated with abusive and nonabusive head trauma: a systematic review. Pediatrics 2012;130(2):315–23.
23. Bilo RAC, Robben SGF, Rijn RR. Forensic aspects of paediatric fractures; differentiating accidental trauma from child abuse. Berlin, Germany: Springer. 2010.
24. Jenny C. Child abuse and neglect: diagnosis, treatment, and evidence. Philadelphia, PA: Saunders. 2010.
25. Hall JR, Reyes HM, Horvat M, Meller JL, Stein R. The mortality of childhood falls. J Trauma 1989;29(9):1273–5.
26. Giardino AP, Lyn MA, Giardino ER. A practical guide to the evaluation of child physical abuse and neglect. New York, NY: Springer Science. 2010.
27. Shugerman RP, Paez A, Grossman DC, Feldman KW, Grady MS. Epidural hemorrhage: is it abuse? Pediatrics 1996;97(5):664–8.
28. Steven C, Gabaeff MD. Challenging the pathophysiologic connection between subdural hematoma. retinal hemorrhage and shaken baby syndrome. West J Emerg Med 2011;12(2):144–58.
29. Mack J, Squier W, Eastman JT. Anatomy and development of the meninges: implications for subdural collections and CSF circulation. Pediatr Radiol 2009;39(3):200–10.
30. Beers MH, Berkow R. The Merck manual, 2nd edn. West Point, PA: Merck & Co. 2004.
31. 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):1290–8.
32. Case ME, Graham MA, Handy TC, Jentzen JM, Monteleone JA. National Association of Medical Examiners *Ad Hoc* Committee on shaken baby syndrome. Position paper on fatal abusive head injuries in infants and young children. Am J Forensic Med Pathol 2001;22(2):112–22.
33. Ichord RN, Naim M, Pollock AN, Nance ML, Margulies SS, Christian CW. Hypoxic-ischemic injury complicates inflicted and accidental traumatic brain injury in young children: the role of diffusion-weighted imaging. J Neurotrauma 2007;24(1):106–18.
34. John SM, Jones P, Kelly P, Vincent A. Fatal pediatric head injuries: a 20-year review of cases through the Auckland coroner's office. Am J Forensic Med Pathol 2013;34(3):277–82.
35. Roach JP, Acker SN, Bensard DD, Sirotnak AP, Karrer FM, Partrick DA. Head injury pattern in children can help differentiate accidental from non-accidental trauma. Pediatr Surg Int 2014;30(11):1103–6.
36. 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;124:1299–306.
37. Love S, Louis D, Ellison DW. Greenfield's neuropathology, 8th edn. London, U.K.: CRC Press, 2008.
38. Feldman KW, Avellino AM, Sugar NF, Ellenbogen RG. Cervical spinal cord injury in abused children, Pediatr Emerg Care 2008;24(4):222–7.
39. Brennan LK, Rubin D, Christian CW, Duhaime AC, Mirchandani HG, Rorke-Adams LB. Neck injuries in young pediatric homicide victims. J Neurosurg Pediatr 2009;3(3):232–9.
40. Cirak B, Ziegfeld S, Knight VM, Chang D, Avellino AM, Paidas CN. Spinal injuries in children. J Pediatr Surg 2004;39(4):607–12.
41. Emerson MV, Jakobs E, Green WR. Ocular autopsy and histopathologic features of child abuse. Ophthalmology 2007;114(7):1384–94.
42. Ewing-Cobbs L, Kramer L, Prasad M, Canales DN, Louis PT, Fletcher JM, et al. Neuroimaging, physical, and developmental findings after inflicted and noninflicted traumatic brain injury in young children. Pediatrics 1998;102(2 Pt 1):300–7.
43. Binenbaum G, Mirza-George N, Christian CW, Forbes BJ. Odds of abuse associated with retinal hemorrhages in children suspected of child abuse. J AAPOS 2009;13(3):268–72.
44. Budenz DL, Farber MG, Mirchandani HG, Park H, Rorke LB. Ocular and optic nerve hemorrhages in abused infants with intracranial injuries. Ophthalmology 1994;101(3):559–65.
45. Binenbaum G, Forbes BJ. The eye in child abuse: key points on retinal hemorrhages and abusive head trauma. Pediatr Radiol 2014;44(4 Suppl):571S–7S.
46. Case ME. Distinguishing accidental from inflicted head trauma at autopsy. Pediatr Radiol 2014;44(4 Suppl):632S–40S.
47. Shiau T, Levin AV. Retinal hemorrhages in children. The role of intracranial pressure. Arch Pediatr Adolesc Med 2012;166(7):623–8.
48. Levin AV. Retinal hemorrhage in abusive head trauma. Pediatrics 2010;126(5):961–70.
49. Keeling JW, Busuttil A. Paediatric forensic medicine and pathology. London, U.K.: Edward Arnold, 2005.
50. Levin AV, Christian CW. Committee on Child Abuse and Neglect, Section on Ophthalmology. The eye examination in the evaluation of child abuse. Pediatrics 2010;126(2):376–80.
51. Royal College of Ophthalmology Child Abuse Working Party. Child abuse and the eye. Eye 1999;13:3–10.
52. Adams G, Ainsworth J, Let Butler, Bonshek R, Clarke M, Doran R, et al. Update from the child abuse working party: Royal College of Ophthalmologists. Eye 2004;18:795–8.
53. Kramer K, Goldstein B. Retinal hemorrhages following cardiopulmonary resuscitation. Clin Pediatr (Phila) 1993;32(6):366–8.
54. Gilliland MG, Luckenbach MW. Are retinal hemorrhages found after resuscitation attempts? A study of the eyes of children. Am J Forensic Med Pathol 1993;14:187–92.
55. Odom A, Christ E, Kerr N, Byrd K, Cochran J, Barr F, et al. Prevalence of retinal haemorrhages in pediatric patients after in-hospital cardiopulmonary resuscitation: a prospective study. Pediatrics 1997;99(6):E3.
56. Kanter RK. Retinal hemorrhages after cardiopulmonary resuscitation or child abuse. J Pediatr 1986;108:430–2.
57. Pham H, Enzenauer RW, Elder JE, Levin AV. Retinal hemorrhage after cardiopulmonary resuscitation with chest compressions. Am J Forensic Med Pathol 2013;34(2):122–4.
58. Lane WG, Dubowitz H, Langenberg P, Dischinger P. Epidemiology of abusive abdominal trauma hospitalizations in United States children. Child Abuse Negl 2012;36(2):142–8.
59. Kemp AM, Dunstan F, Harrison S, Morris S, Mann M, Rolfe K, et al. Patterns of skeletal fractures in child abuse: systematic review. BMJ 2008;337:a1518–26.
60. Jayakumar P, Barry M, Ramachandran M. Orthopaedic aspects of paediatric non-accidental injury. J Bone Joint Surg Br 2010;92(2):189–95.
61. Maguire SA, Kemp AM, Lumb RC, Farewell DM. Estimating the probability of abusive head trauma: a pooled analysis. Pediatrics 2011;128(3):e550–64.
62. Reece RM, Sege R. Childhood head injuries: accidental or inflicted? Arch Pediatr Adolesc Med 2000;154(1):11–5.
63. Banaschak S, Janßen K, Schulte B, Rothschild MA. Rate of deaths due to child abuse and neglect in children 0–3 years of age in Germany. Int J Legal Med 2015;129(5):1091–6.

Additional information and reprint requests:
Serenella Serinelli, M.D.
Department of Anatomy, Histology, Forensic Medicine and Orthopedics
"Sapienza" University of Rome
Viale Regina Elena 336
Rome 00185
Italy
E-mail: s.serinelli@gmail.com