Retinal Hemorrhages in Children Following Fatal Motor Vehicle Crashes

A Case Series

Jane D. Kivlin, MD; Melissa L. Currie, MD; V. Jordan Greenbaum, MD; Kenneth B. Simons, MD; Jeffrey Jentzen, MD

Objective: To demonstrate the severity of ocular findings in young children who died of injuries due to motor vehicle crashes.

Methods: Case series of 10 children younger than 3 years who were fatally injured in motor vehicle crashes between January 1, 1994, and December 31, 2002. All children underwent autopsy that included eye examination. All available medical and autopsy records, pathology slides and photographs, and police and traffic department reports were reviewed for each case.

Results: Eight patients had retinal hemorrhages, which extended into the periphery in 13 eyes and were bilateral in 7 patients. Three patients had elevated circular retinal folds. Six patients had hemorrhages below the internal limiting membrane, but no patients had deeper splitting of the retina. Nine patients had optic nerve sheath hemorrhages.

Conclusion: The association of extensive, sometimes severe, ocular hemorrhages with fatal accidental trauma, compared with previous reports of accidental trauma with no or few hemorrhages, indicates the severity of injury required to cause hemorrhages of this magnitude.

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Table. Incident Details and Autopsy Findings in 10 Children Fatally Injured in Motor Vehicle Crashes

<table>
<thead>
<tr>
<th>Patient No./Age</th>
<th>Details of Crash</th>
<th>Cause of Death</th>
<th>Head Injury</th>
<th>Restraint</th>
<th>Optic Nerve Findings</th>
<th>Retina Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/13 wk</td>
<td>Head-on collision; car of drunk driver flipped onto patient's car; another child in car also killed, not examined</td>
<td>Brain laceration, hemotorax</td>
<td>2 Depressed skull fx, midbrain parenchymal laceration</td>
<td>Forward facing in car seat meant to be rear facing only</td>
<td>Bilateral sheath hemorrhage</td>
<td>R eye: extensive, innumerable RHs to ora serrata at all levels, multiple sub-ILM hemorrhages; L eye: normal</td>
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<tr>
<td>2/9 mo</td>
<td>Patient's car struck utility pole; patient struck windshield</td>
<td>Brain injury, liver laceration, pulmonary hemorrhage</td>
<td>Multiple linear skull fx, brain contusions</td>
<td>None; sitting on parent's lap in front seat</td>
<td>Bilateral sheath hemorrhage</td>
<td>R eye: circular retinal fold, confluent RHs at all levels to ora serrata, dome-shaped sub-ILM hemorrhage and vitreous hemorrhage; L eye: innumerable RHs at all levels to ora serrata; bilateral extensive RHs at all levels to ora serrata, sub-ILM hemorrhage</td>
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<tr>
<td>3/18 mo</td>
<td>Automobile-pedestrian; struck and dragged</td>
<td>Brain injury, liver laceration, pulmonary hemorrhage</td>
<td>Severe cerebral edema, SDH, IVH, no skull fx</td>
<td>NA</td>
<td>Bilateral sheath hemorrhage</td>
<td>Bilateral extensive RHs to ora serrata and sub-ILM hemorrhage</td>
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<tr>
<td>4/2 y</td>
<td>3150 kg of cargo from oncoming truck struck patient's car, forcing it backward; driver also killed</td>
<td>Cerebral edema</td>
<td>SDH, no skull fx</td>
<td>Correctly used forward-facing car seat in back seat</td>
<td>Bilateral sheath hemorrhage</td>
<td>R eye: peripapillary, a few peripheral intraretinal RHs; L eye: peripapillary intraretinal RHs only; no sub-ILM RHs in either eye</td>
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<tr>
<td>5/6 mo</td>
<td>Patient's car struck at 90° with intrusion by pickup truck of drunk driver; driver also killed</td>
<td>Cerebral edema</td>
<td>Skull fx, IVH, SDH, SAH</td>
<td>Rear, in car seat, direction facing unknown</td>
<td>Bilateral sheath hemorrhage</td>
<td>Bilateral extensive RHs, confluent in some areas, at all levels to ora serrata, sub-ILM hemorrhage in both eyes</td>
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<tr>
<td>6/5 mo</td>
<td>Near head-on collision; both cars traveling &gt; 88 km/h; drunk driver of other car crossed meridian</td>
<td>Head injury, splenic tear</td>
<td>Multiple skull fx, cerebral contusions and lacerations</td>
<td>Correctly strapped, rear facing in middle of rear seat</td>
<td>Bilateral sheath hemorrhage</td>
<td>Bilateral extensive RHs to ora serrata, no sub-ILM hemorrhage in either eye</td>
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<tr>
<td>7/15 mo</td>
<td>Rollover crash; single-car accident</td>
<td>Head injury</td>
<td>L parietal lobe hemorrhage, diffuse cerebral edema, IVH, no skull fx</td>
<td>Unknown; was ejected from car</td>
<td>Bilateral sheath hemorrhage</td>
<td>Bilateral extensive RHs at all levels to ora serrata, sub-ILM hemorrhage; L eye: circular retinal fold</td>
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<tr>
<td>8/4 mo</td>
<td>Patient's car struck at 90° with 30.5-cm indentation by car of drunk driver</td>
<td>Head injury, grade V splenic laceration, lung contusions</td>
<td>Depressed skull fx with extrusion of brain, contusions and lacerations of brain, SDH extending into spinal cord</td>
<td>Forward facing in car seat meant to be rear facing only</td>
<td>Bilateral sheath hemorrhage</td>
<td>R eye: circular retinal fold; bilateral confluent RHs to ora serrata, sub-ILM hemorrhage, vitreous hemorrhage</td>
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<tr>
<td>9/7 mo</td>
<td>Pedestrian hit by illegally drag-racing car</td>
<td>Head injury</td>
<td>Multiple skull fx, cerebral avulsion, laceration</td>
<td>NA</td>
<td>L eye: sheath hemorrhage</td>
<td>No retinal abnormalities</td>
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<tr>
<td>10/22 mo</td>
<td>Ran into street; struck by car leaving curb</td>
<td>Head injury</td>
<td>Basilar skull fx, R frontal lobe laceration</td>
<td>NA</td>
<td>None</td>
<td>No retinal abnormalities</td>
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Abbreviations: fx, fracture; ILM, internal limiting membrane of the retina; IVH, intraventricular hemorrhage of the brain; L, left; NA, not applicable; R, right; RHs, retinal hemorrhages; SAH, subarachnoid hemorrhage of the brain; SDH, subdural hemorrhage of the brain.

*The types of force in all cases were impact and acceleration/deceleration injury.

The periphery in 13 eyes and were bilateral in 7 patients. Two children had no hemorrhages, and another had only a few peripapillary hemorrhages in 1 eye. Nine patients had optic nerve sheath hemorrhages, which were bilateral in 8. Three patients had elevated circular retinal folds. Six patients had dome-shaped hemorrhages just below the internal limiting membrane (ILM), but no patients were found to have deeper splitting of the retinal layers.
The most common traumatic mechanism associated with retinal hemorrhaging of any severity—but particularly the most severe forms where the hemorrhages extend to the ora serrata—is rotational acceleration/deceleration type injury. This is the mechanism involved in nonaccidental childhood neurotrauma (also known as shaken baby syndrome).

Multiple reports including children of all ages have demonstrated the infrequency of retinal hemorrhaging with known accidental trauma of various mechanisms, even with skull fractures. In prospective, possibly overlapping, studies of accidentally injured nonnewborn children, only 69 of at least 776 children examined (8.9%) had retinal hemorrhages. Retrospective studies have shown similar results.

Of patients described in the literature, 38 had mild hemorrhages that did not extend to the ora serrata. Reports concerning an additional 23 patients did not include enough description of their hemorrhages to determine whether the hemorrhages were mild or severe. The 7 patients known to have hemorrhages extending to the ora serrata died of their injuries. Three patients died of high-energy, rotational forces similar to those seen in nonaccidental childhood neurotrauma. Four other patients died of crush injuries to the head caused by toppling television sets, the fall of another child onto the head of the victim, or an MVC. Plunkett retrospectively reported 4 children with retinal hemorrhages who died of playground injuries. Their hemorrhages were found by a neurosurgeon or by pediatric intensivists, details regarding the extent, type, and number of hemorrhages are uncertain compared with the autopsy findings reported herein. In each investigation, a best estimate was that the injuries were accidental rather than inflicted, although some were not witnessed, particularly by an adult. That the accidents were fatal indicates the severity of the forces delivered to the children’s heads; that two-thirds of those examined had retinal hemorrhages is consistent with severe injury.

The most commonly suggested mechanisms for retinal hemorrhages in children younger than 3 years, particularly in nonaccidental head trauma, are mechanical vitreous traction on the retina and a sudden increase in venous pressure in the retinal vessels. The mechanical theory suggests that traction on the retina due to the motion of the vitreous body during violent rotational acceleration/deceleration forces causes direct damage to the retina and its blood vessels. The attachment of the vitreous body in children is strongest at the posterior pole, along the vessels, and at the periphery, which may explain the distinctive distribution often seen in the most severe retinal hemorrhaging and retinal detachment in nonaccidental neurotrauma, similar to Figure 1. The observed attachment of the ILM to the peak of the circular retinal fold and the finding of orbit tissue injury during autopsy examination of children with nonaccidental neurotrauma and accidental death have also been cited as evidence of mechanical forces.

Some well-documented cases of abusive neurotrauma have shown no sign of direct head impact on careful autopsy examination of the layers of the head. Perpetrator confessions have corroborated the shaking mechanism suspected. The children we studied had severe acceleration/deceleration injuries consistent with the mechanical theory for retinal hemorrhages. Patient 7 had an elevated retinal fold but did not have skull fractures. Most elevated retinal folds reported in children have been associated with abusive neurotrauma. These

*References 3, 8, 16, 20, 21, 23, 25, 27, 30, 32, 39.

Figure 1. Patient 3, right eye (2 views). Many nonconfluent hemorrhages extend to the ora serrata.
hemorrhages in 1 patient who had been in an MVC. Intracranial hemorrhage of various causes found only 5 small hemorrhages in children. A study of the eyes in children with intracranial hemorrhage supports this, however, because Terson syndrome is rarely seen in children.\textsuperscript{41} In at least 1 trauma patient, a very large, dome-shaped sub-ILM hemorrhage has been found spanning the macular region encompassed by the circular retinal fold.\textsuperscript{4} The 3 children reported herein to have elevated circular retinal folds did not have this large sub-ILM hemorrhage (patients 2, 7, and 8) (Figure 2). Emerson and coauthors\textsuperscript{32} have proposed that sustained venous stasis and leakage from retinal vessels can lead to elevated circular retinal folds in non-accidental neurotrauma. Our patients demonstrated that abrupt injury can cause these folds as well.

A sudden increase in venous pressure in the eye is the other primary mechanism proposed to cause retinal hemorrhages in nonaccidental neurotrauma. Less evidence supports this, however, because Terson syndrome is rarely seen in children. A study of the eyes in children with intracranial hemorrhage of various causes found only 5 small hemorrhages in 1 patient who had been in an MVC.\textsuperscript{31} Increased venous pressure secondary to Valsalva maneuvers or chest compression\textsuperscript{32-35} does not seem to be a likely cause of intraocular hemorrhage because these processes cause very few or no retinal hemorrhages in children.\textsuperscript{36-41} Crush injuries may cause retinal hemorrhages because of increased intracranial and intraocular venous pressure. However, 9 patients who died of their crush injuries did not have retinal hemorrhages or had only a few posterior hemorrhages.\textsuperscript{37} and 11 survivors did not have any hemorrhages.\textsuperscript{7}

Three accidentally crushed children were reported to have large hemorrhages and retinoschisis.\textsuperscript{3,4,9} In our patients, there were sub-ILM hemorrhages and no deeper splitting of the retina. In 3 patients who underwent vitrectomies for large dome-shaped macular hemorrhages associated with a retinal fold or pigmentary changes around the macula, the excised anterior wall of the cyst contained ILM.\textsuperscript{62} These patients included a 17-year-old and 4-year-old with Terson syndrome of unknown cause and a 5-month-old with shaken baby syndrome. A postmortem examination in a 7-month-old with shaken baby syndrome also showed a hemorrhagic cyst enclosed by ILM.\textsuperscript{94}

Many abused children with retinal hemorrhages have skull fractures that must have been caused by impact injuries but rarely to the point of classifying them as crush injuries.\textsuperscript{21,63} Seven of the patients reported herein had skull fractures (patients 1, 2, 5, 6, 8, 9, and 10), and 5 (patients 1, 6, 8, 9, and 10) had depressed skull fractures or fractures with brain lacerations. In the police reports, there was no indication that the children were crushed between 2 surfaces, as has been the case in patients reported to have an object or person fall on their head.\textsuperscript{3,4,9} Three patients had no skull fractures (patients 3, 4, and 7); their injuries largely resulted from acceleration/deceleration mechanisms. Impact and acceleration/deceleration mechanisms can combine to cause retinal hemorrhage, as in the “tin ear syndrome”\textsuperscript{64} and nonaccidental childhood neurotrauma.\textsuperscript{31}

Our patients had injuries that involved acceleration/deceleration mechanisms, but they also had sudden head injuries and intracranial bleeding; thus, both proposed mechanisms for retinal hemorrhages could apply. Patient 9, who died of severe brain injury on the day of the accident, had only optic nerve sheath hemorrhage. Patient 4, who had only mild peripapillary hemorrhages in the left eye, died 7 days after the injury. Retinal hemorrhages were noted by the intensive care attending physician 1 day before death, but the extent and laterality of the hemorrhages were not noted. Some retinal hemorrhages could have resolved before death.

It is not clear why some patients who were fatally injured by accident or intent do not have retinal hemorrhages. Some of these patients died immediately, negating the possibility that hemorrhages had been present but resolved before death. The particular type of trauma and where the forces were sustained must account for the variation in retinal findings.

All of our patients died after being subjected to extremely severe forces involving rapid deceleration with a rotational (whiplashlike) component, similar to that described in nonaccidental childhood neurotrauma. The extent and severity of the retinal hemorrhages, when compared with the rare and mild hemorrhages in other less severely accidentally injured patients, indicate that more severe trauma causes more severe eye findings. These were all extremely high-force injury mechanisms that far exceed those involved in common (or even uncommon) household accidents. This supports previous conclusions\textsuperscript{2,8,21,65} that, in the absence of a known major accidental injury involving severe intracranial trauma, such as a crush injury or high-force MVC, extensive retinal hemorrhages are highly indicative of occult, severe intentional injury.
thology, Medical College of Wisconsin, 925 N 87th St, Milwaukee, WI 53226 (jkivlin@mcw.edu).

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