Stephen D. Cohle,[1] M.D.; Dean A. Hawley,[2] M.D.; Kathryn K. Berg,[3] M.D.; Eric L. Kiesel,[4] M.D., Ph.D.; and John E. Pless,[5] M.D.

Homicidal Cardiac Lacerations in Children

REFERENCE: Cohle, S. D., Hawley, D. A., Berg, K. K., Kiesel, E. L., and Pless, J. E., **"Homicidal Cardiac Lacerations in Children,"** *Journal of Forensic Sciences,* JFSCA, Vol. 40, No. 2, March 1995, pp. 212–218.

ABSTRACT: We report six cases of intentionally inflicted cardiac laceration. The victims ranged in age from 9 weeks to 2 $^1/_2$ years. Five victims were girls and in five cases the right atrium was lacerated. The left ventricle was lacerated in the other case. In the three cases with a confession, one victim each was struck with a fist, stomped, and kicked. Four patients had rib fractures, with at least two fractures in each case. Cardiac rupture from blunt trauma most commonly results from compression of the heart between the sternum and vertebral column, but may also occur from compression of the abdomen or legs, deceleration, blast injury, puncture of the heart by a fractured rib, and rupture through a resolving contusion. Accidentally acquired cardiac lacerations usually result from motor vehicle accidents or similarly severe forces. In children there are neither well documented cases of cardiac laceration nor of rib fractures from cardiopulmonary resuscitation. Cardiac lacerations, as with other types of severe trauma acquired at home, are almost never accidental.

KEYWORDS: pathology and biology, heart injuries, child abuse, homicide, wounds, nonpenetrating

The diagnosis of child abuse can be very difficult, requiring evaluation of the caretaker's story with the injuries observed at autopsy. Most fatal injuries are inflicted to the head or abdomen. In this paper we report blunt force cardiac injuries in six fatally abused children. The literature was reviewed to determine the mechanisms and causes of blunt force injury to the heart and the types of cardiac injuries reported from cardiopulmonary resuscitation (CPR).

Case 1 (A92-494)

The patient was a $2^1/_2$-year-old black girl who, according to her mother's boyfriend was found unresponsive at the bottom of a flight of 13 carpeted stairs. Upon arrival of the paramedics, the child was in cardiopulmonary arrest. She was intubated and given CPR and transported to a local hospital where she was pronounced dead approximately one hour and 10 minutes after she was found. The only individuals performing chest compressions were police officers at the scene and the paramedics. These individuals, who had had CPR training, reported using the index and middle fingers of one hand over the index and middle fingers of the other hand to perform the chest compressions exerting a mild amount of pressure.

Significant autopsy findings included multiple contusions in the center of the chest covering an area measuring 3.8 cm in diameter. Internally there was a transmural 1 cm laceration of the apex of the left ventricle which was associated with a 2 cm endocardial laceration of the interventricular septum (Fig. 1 and Fig. 2). There was a 0.8 cm in length epicardial laceration of the apex of the right ventricle. There were 10 mL of blood in the pericardial sac and there was a 3.5 cm pleuropericardial laceration adjacent to the inferior vena cava (Fig. 3). This was not transmural throughout; in its midportion there was a 1.0 cm transmural laceration communicating with the right pleural cavity, which contained 200 mL of blood. The right lung was atelectatic. There were fractures of the posterior aspect of the right 10th and 12th ribs, each of which was surrounded by about 1 mL of hemorrhage.

There was a 2 cm laceration of the right margin of the caudate lobe of the liver. This laceration extended 1.5 cm into the liver

FIG. 1—*Case 1. Apex of heart showing transmural laceration of left ventricle* (large arrow) *and superficial right ventricular laceration* (small arrow).

Received for publication 23 May 1994; revised manuscript received 20 July 1994; accepted for publication 21 July 1994.

[1] Blodgett Memorial Medical Center, Grand Rapids, MI.

[2] Associate Professor of Pathology, Indiana University School of Medicine, Indianapolis, IN.

[3] Assistant Chief Medical Examiner, Hennepin County, Minneapolis, MI.

[4] Chief Medical Examiner, Snohomish County Medical Examiner Office, Everett, WA.

[5] Clyde G. Culbertson Professor of Pathology, Indiana University of Medicine, Indianapolis, IN.

Presented in part at the American Academy of Forensic Sciences meeting, San Antonio, Texas, February 14–19, 1994.

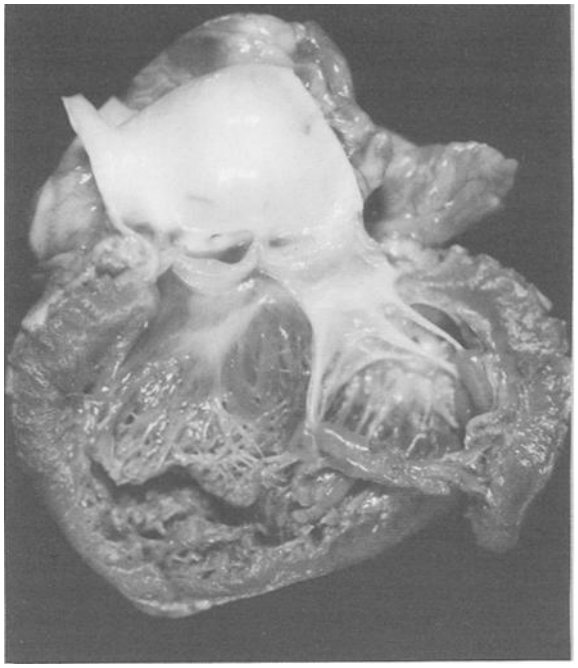

FIG. 2—*Case 1. Endocardial surface of left ventricle showing W-shaped laceration.*

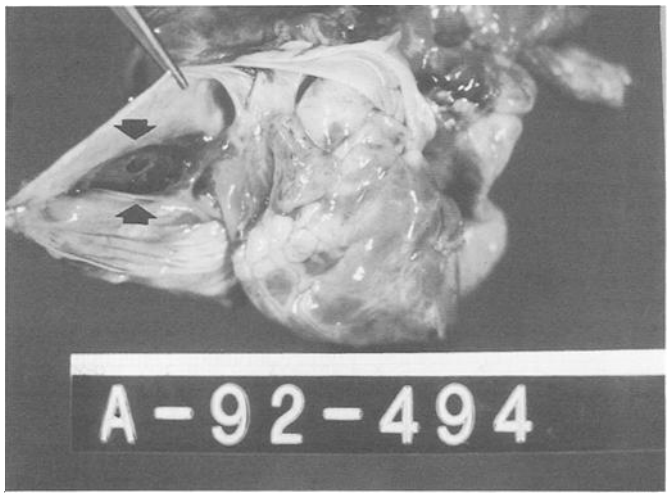

FIG. 3—*Case 1. Right side of pericardial sac retracted from heart to show teardrop-shaped laceration on cardiac surface* (arrows). *Defect on pleural side is smaller and located in center of parietal pericardial laceration* (between arrows).

parenchyma. There was a 0.8 cm laceration of the posteromedial portion of the left lobe and a 0.6 cm laceration of the superior medial portion of the quadrate lobe. There were approximately 5 mL of periadrenal hemorrhage on the right and 10 mL on the left. There was a 2 cm × 1 cm area of hemorrhage on the superior medial aspect of the left hemidiaphragm, about 10 mL of hemorrhage into the hilum of the spleen, and a slight amount of hemorrhage within the mesenteric border of the jejunum.

Grossly the heart contained no natural disease. Microscopically, sections from the apex of the heart showed contraction bands within the myocardium lining the laceration. Several sections, primarily the interventricular septum, contained interstitial fibrosis (Fig. 4 and Fig. 5). This did not occupy a significant volume of the myocardium, and at the closest, extended to within 4 mm of the right ventricular apical laceration. Iron stains of this area of fibrosis revealed abundant hemosiderin-laden macrophages, but none were seen in the laceration. There was no acute inflammatory process, such as myocarditis. Sections from the atria, right ventricle, and most of the sections from the left ventricle showed normal myocardium.

The defendant was convicted of second degree murder.

Case 2 (A931-1556)

The initial history given by the father was that he was awakened by this 9-week-old baby's cries at about 3 o'clock in the morning. He tried to give the baby a pacifier, changed the baby's diaper,

FIG. 4—*Case 1. Interventricular septum showing interstitial fibrosis. Original magnification ×40.*

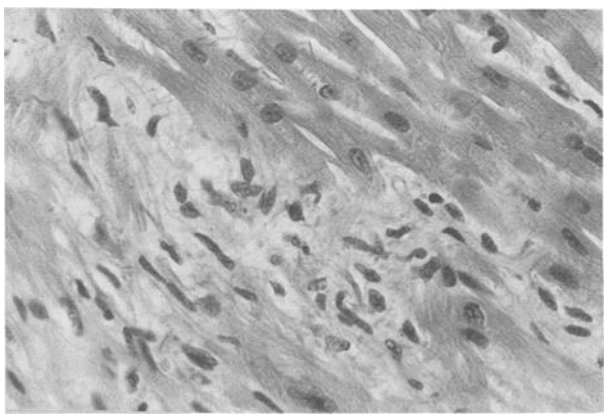

FIG. 5—*Case 1. Higher power view of interventricular septum showing fibrosis with absence of acute myocardial fiber destruction. Original magnification ×400.*

and tried to feed him but he would not take a bottle. He then put the baby between the baby's mother and him and the father then fell asleep. The father was awakened later in the morning by the mother, who had discovered the baby to be dead. CPR was not performed. Upon further questioning the father stated that as he was carrying the baby he tripped on a shoe and dropped the child who struck his head on a floor fan. The baby then became very quiet and his "eyes became very large." The father did not notify the mother or call an ambulance because he was afraid he would be accused of child abuse.

Pertinent autopsy findings included a 3.5 cm subgaleal contusion in the right parietal scalp. Beneath this was a stellate fracture of the parietal bone. There was a second linear fracture of the parietal bone which was in the coronal plane. There were diffuse cerebral edema, subarachnoid hemorrhage, and 10 mL of subdural hemorrhage on the right. The eyes did not exhibit retinal hemorrhage.

There was a 7 mm transmural laceration of the anterior superior right atrium located beneath the atrial appendage (Fig. 6). The right atrial endocardium just above and anterior to the fossa ovale was lacerated (Fig. 7). There were 20 mL of blood in the pericardial sac.

There were fractures of the right second through the eighth ribs laterally and the left third through the ninth ribs laterally. There was a healed fracture with callus formation of the posterior portion of the left ninth rib. There were multiple thymic contusions and there were two contusions of the right lung.

The posterior medial left lobe of the liver contained a 1.2 cm laceration on the capsule and a 2.0 intraparenchymal laceration.

The father subsequently confessed that the baby awoke crying at 3 a.m. The infant refused a bottle and would not go back to sleep. The father then struck the baby once on the chest with his fist while the baby was lying in the crib. He then shook him violently, his head hitting twice on the headboard of the crib.

The father claimed to not know how the other injuries, including the healing rib fracture, occurred.

The father pled no contest to second degree murder.

Case 3 (L85-271)

The father of this 7-month-old white female infant first stated that he was holding her and as he was bending down her head hit a wooden service bar. When he checked her several minutes later she was comatose and cyanotic. Later he said that the baby fell and struck her head on a table. He told a neighbor that he had dropped the baby. The father performed mouth-to-mouth resuscitation. The child was pronounced dead in an emergency room shortly after having been found unresponsive.

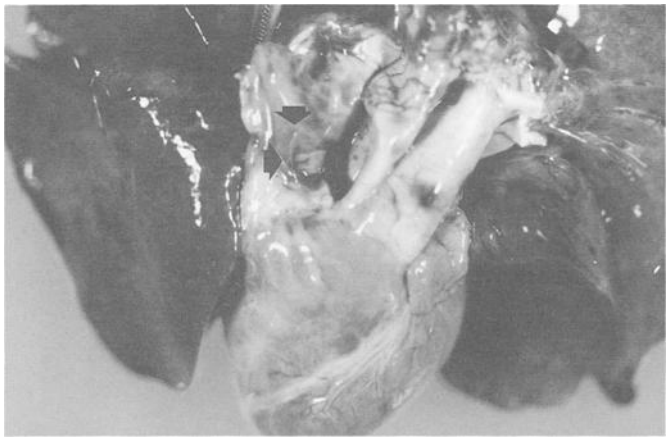

FIG. 6—*Case 2. Right atrial laceration* (arrows). *Atrial appendage is retracted to expose laceration. The endocardium of the adjacent atrial wall is visible through the defect.*

FIG. 7—*Case 2. Right atrial endocardium showing laceration* (arrow) *just superior and anterior to the fossa ovale.*

Pertinent autopsy findings included 90 mL of freshly clotted blood in the pericardial sac, causing tamponade. The heart contained a 3 cm laceration of the right atrium separating the right atrial appendage and wall of the right atrium from the right ventricular outflow track.

Other gross autopsy findings included recent and old scalp contusions, contusions of the left anterior neck muscles and thyroid gland, contusions of the musculature of the posterior neck and back, multiple fractures of the spinal column, and epidural hemorrhage of the upper cervical and upper lumbar spinal cord. There were bilateral recent pulmonary contusions and a healed fracture of the distal right radius.

Microscopically there was organized granulation tissue on the visceral pericardium. At the site of the atrial laceration there was a healing contusion consisting of degenerating myocardial fibers mixed with granulation tissue including fibroblasts, macrophages, lymphocytes, and degenerating red blood cells.

The father pled guilty to involuntary manslaughter.

Case 4 (A503-90)

This 11-month-old white female infant was found unresponsive on the floor by the babysitter, who had placed her there moments previously. The babysitter called paramedics, who performed CPR. The baby was pronounced dead in a local hospital emergency department.

Significant autopsy findings included a 1.6 cm by 0.8 cm laceration of the posterior wall of the right atrium and anterior wall of

the inferior vena cava at its entrance to the atrium (Fig. 8). There was subpleural hemorrhage beneath the right 7th rib in the midaxillary line and contusion in the intercostal muscle between the 6th and 7th ribs. There were 80 to 100 ml of hemopericardium. There were contusions of the bases of the lungs. The anterior margin of the liver contained a 2.5 cm subcapsular laceration adjacent to the falciform ligament. There was a slight amount of hemorrhage in the mesenteric and retroperitoneal fat. The right external ear was contused, there was a contusion over the right mandible, and there were abrasions over the right inferior orbital rim and anterior to the left ear.

The babysitter was acquitted after a trial in which a forensic pathologist testifying for the defense stated that the injuries could have been received from CPR.

Case 5 (ME91-3177)

This 15-month-old black female child's babysitter stated that the child was found unresponsive and apneic. The babysitter claimed to have been awakened by another child for whom she was caring and to have been informed that the victim had fallen, bumped her head and lost consciousness. The babysitter administered mouth-to-mouth respirations. Resuscitation was taken over by the police and then by paramedics, who performed mouth-to-mouth respirations and standard two-finger chest compressions. She was taken to the emergency department of a local hospital where despite additional resuscitation she was pronounced dead one hour and 5 minutes after the initial 911 call.

The child had been previously well except for possible cow's milk allergy. Six weeks before death she was evaluated at a hospital for first and second degree burns of the right side of her head and the right hand, which were said to have resulted from the "explosion" of a bowl of hot grease.

At autopsy significant external findings included faint facial contusions, a faint contusion of the back, and an oval patterned contusion of the forearm. In the buccal cavity there were lacerations of the superior frenulum and the junction of the buccal mucosa with the right mandibular ridge.

Internally, there were subgaleal contusions as well as bilateral fractures of the 2nd through the 8th ribs anteolaterally, the right ribs 6–8 laterally, and the posterior aspect of the right 6th rib. There was a partial thickness laceration of the superior vena cava at its junction with the right atrium, and a 0.8 cm transmural laceration of the inferior vena cava at its junction with the right atrium (Fig. 9). The superior portion of the right lobe of the liver contained a laceration consistent with having been caused by compression of an overlying rib into the parenchyma. There was hemorrhage into the soft tissues of the porta hepatis and mesenteric root. There were 40 mL of liquid blood within the pericardial sac, 100 mL in the right pleural cavity, and 100 mL within the peritoneal cavity.

When confronted with the autopsy findings the babysitter admitted that she had stomped on the baby when she continued crying after her diaper was changed. The child immediately became unresponsive, prompting the babysitter to dispatch another child to summon the infant's mother to the babysitter's home. At that time 911 was called.

The babysitter pled guilty to second degree murder and was sentenced to 150 months in prison.

Case 6 (87-453)

This one-year-old white female had been riding in an automobile with her mother's boyfriend when she made "choking" sounds

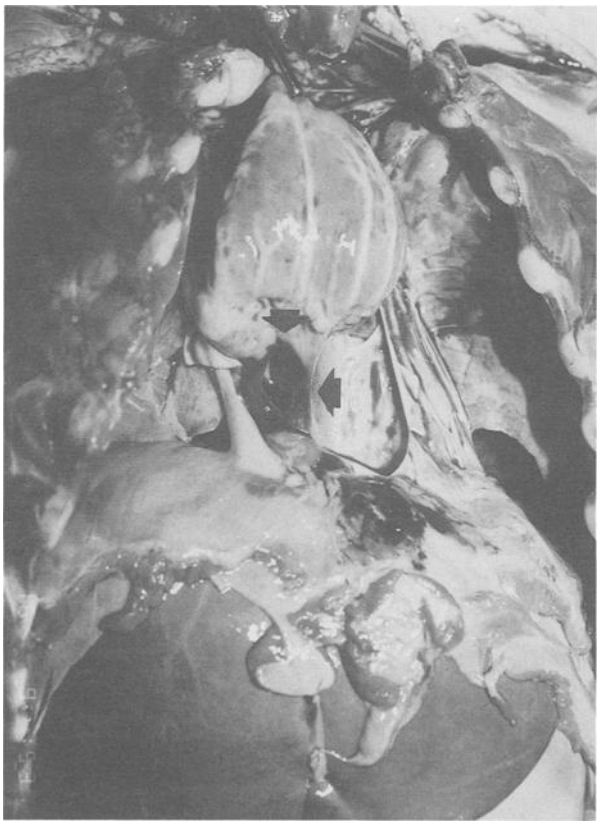

FIG. 8—*Case 4. Heart is reflected upward to show right atrial laceration* (arrows).

FIG. 9—*Case 5. Apex of heart is retracted upward to show the laceration at the junction of the inferior vena cava and right atrium.*

TABLE 1—*Cardiac laceration cases.*

Case	Origin	Age	Sex	Chamber	Confessed Mechanism	Fractured Ribs	Conviction
1	Michigan	2 1/2 yr	F	LV	none	yes	2nd degree murder
2	Michigan	9 weeks	M	RA	struck baby with fist	yes	2nd degree murder
3	Indiana	7 months	F	RA	none	no	involuntary manslaughter
4	Indiana	11 mos	F	RA	none	no	acquitted
5	Minnesota	15 mos	F	RA	stomping on baby	yes	2nd degree murder
6	Washington	12 mos	F	RA	kicked baby	yes	2nd degree murder

NOTE: RA = right atrium, LV = left ventricle.

and stopped breathing, the boyfriend stated. He did not perform CPR. Paramedics arrived within 4 minutes and performed CPR, including chest compressions using two fingers. She was pronounced dead in a hospital emergency department.

Pertinent autopsy findings included a 3/4" abrasion on the vertex of the head, a 1/2" abrasion on the right occipital scalp, and a contusion of the lumbar back.

Internal examination of the head revealed three extensive areas of recent and old subgaleal contusion beneath the frontal-parietal scalp bilaterally. There were a one cm fracture of the right parietal bone and a 7 mm fracture of the right side of the occipital bone. There was a 3.5 cm × 3.0 cm area of old contusion involving the medial superior portion of the frontal lobes. There was a 1/2 × 3/8 inch area of old epidural hemorrhage over the left occipital bone.

The right atrium of the heart was lacerated and the pericardial sac was filled with blood. The right 7th and 9th ribs were fractured posteriorly. There was contusion of the inferior portion of the right lobe of the thymus gland.

Abdominal injuries included contusion of the head and body of the pancreas, and laceration of the lesser omentum at the lesser curvature of the stomach.

The mother's boyfriend later admitted drop-kicking the infant across the room, where she struck her head against a wall. He pled guilty to second degree murder.

Discussion

The six cases are summarized in Table 1.

In summary, the ages of our six cases ranged from 9 weeks to 2 1/2 years, there were five females and one male, and in five of the six patients the ruptured chamber was the right atrium. Confessed mechanisms included striking the baby with the assailant's fist, stomping on the infant, and drop-kicking the infant. Ribs were fractured in four out of six victims. The child described in Case 1 had a healed myocardial contusion and the child described in Case 2 had a healing myocardial contusion.

Significant blunt cardiac injury is relatively uncommon. In a 16 year period Golladay et al. [*1*] identified 20 cases of cardiac injury in children under 18 years; only four of these resulted from blunt trauma. Of these, three had cardiac contusions and one had a right atrial rupture. Of 20,000 patients older than 10 years, Fulda and associates [2] found 59 patients with cardiac lacerations.

There are several mechanisms of blunt force-induced cardiac rupture (Table 2). A direct blow to the anterior chest is the most common mechanism of rupture. Compression of the heart between the sternum and ribs is especially common in individuals with pliable chests, such as children. Trunk or leg compression causes increased hydrostatic pressure in the heart. The freely movable heart, tethered by the great vessels, undergoes tears of the atria at their venous attachments with sudden acceleration/deceleration. The pointed end of a fractured rib or sternum can puncture the heart. Blast forces can impact against the heart, similar to direct blows. A cardiac chamber with a transmural contusion may rupture as the injured myocardium becomes necrotic [*3–8*]. Ventricular distention and thus, rupture (including the septum) is most likely at the end of diastole, while the atria are more vulnerable late in systole; in both of these situations the valves are closed [*2,9*].

Whatever the mechanism, the rate at which the pressure is applied to the heart is a critical determinant in whether rupture will occur. If a blood-filled cardiac chamber is compressed slowly, the applied energy can be absorbed by deformation without rupture, but with rapid loading (application of pressure) the chamber cannot change shape fast enough to accommodate the increased pressure and will rupture [*10*].

There are numerous causes of cardiac lacerations. In the largest autopsy series [*3*], of 105 cases in which information was available, 38 were run over by wagons, 22 were crushed between two objects, 17 suffered a direct blow to the chest, 12 were struck by a falling object, 8 were kicked by a horse, 3 were injured in an explosion, 2 were struck in the sternum by a bullet, and one each fell, was jumped on by playmates, and was engulfed by a sandbank. In the largest clinical series [*2*], of 59 patients, 40 were injured in a motor vehicle accident (MVA), 6 in a motorcycle crash, 4 were pedestrians struck by motor vehicles, 4 were crushed, 3 fell, and one each was kicked by a horse and struck by a crane. Each of the above series contained patients of all ages.

Of 14 cases in children 15 years and younger with cardiac lacerations, 3 were in MVAs [*11–13*], 3 were struck or stomped in the abdomen [*14*], and one each was jumped on while on a sled [*4*], a pedestrian hit by a car [*15*], a bicyclist who struck her precordium on the handlebar during a fall [*16*], fell 2.5 meters onto a hard surface [*7*], kicked in the chest by an adult [*17*], thrown off a rapidly moving sled, landing with great force [*18*], hit by a tree limb [*9*], hit in the chest by a 23 kg barbell that fell 1 meter [*19*], and fell from the first floor of a building [*8*].

Four of the cases of cardiac laceration mentioned in the preceding paragraph were caused by assaultive blunt trauma. Cumberland et al. [*14*] reported endocardial lacerations of the right atrium in three fatally abused children, aged four months, eleven months, and three years. All were struck in the abdomen, two with a foot

TABLE 2—*Mechanisms of cardiac rupture* [3–7].

Direct blow
Compression between sternum and vertebrae
Compression of trunk or legs
Acceleration/deceleration
Penetration by fractured ribs or sternum
Blast injury
Contusion leading to necrosis

and one with a fist. In these cases the mechanism of endocardial laceration was transmission of hydrostatic force through the inferior vena cava to the right atrium. These authors found right atrial endocardial laceration in three teenagers injured in MVAs (two passengers and one pedestrian) and concluded that the amount of force required to cause intimal laceration of the right atrium is of the same order of magnitude as that in an MVA. Rees and associates [*17*] described a five-year-old girl who was kicked in the chest by her father two weeks before admission to the hospital. She had no chest bruises on admission and there were no rib fractures. At surgery she was found to have a 1.5 cm defect in the muscular interventricular septum near the apex. She recovered and was discharged alive and well.

Delayed rupture was reported in seven cases. The interval between rupture and clinical presentation ranged from 12 hours [*13*] to 14 months [*15,16*]. In three cases [*7,15,16*] the left ventricle was injured and the other four had traumatic ventricular septal defects (VSDs) [*8,13,17,18*].

Review of large clinical [*2,20*] and autopsy [*3,5*] series of patients of all ages sustaining blunt cardiac trauma shows no one chamber involved more than the others (Table 3). Whether the atria or ventricles are ruptured depends on the phase of the cardiac cycle when the trauma is inflicted (vide supra).

The chambers injured in cases of children 15 years and younger with cardiac lacerations were described by 13 authors reporting 16 cases. The right atrium was involved in five cases [*1,14,19*], including the three cases described by Cumberland [*14*] where intimal lacerations were present. The right ventricle was lacerated in one case [*4*], the interventricular septum in six cases [*8,9,12,13,17,18*], and the left ventricle in four [*7,11,15,16*]. Smith's patient had an aneurysm that was surgically resected [*15*] and O'Reilly et al.'s patient had a pseudoaneurysm that was closed at surgery [*16*].

Pericardial laceration from blunt trauma occurs less commonly than cardiac chamber laceration. Fulda et al. [*21*] have the most detailed series. The ages of the victims were not specified. They observed 22 pericardial lacerations out of 20,000 patients. Sixteen resulted from MVAs, three from motorcycle crashes, two from falls, and one from crush injuries. The left pleuropericardial surface was lacerated in 64%, the diaphragmatic surface in 18%, the right pleuropericardium in 9%, and the superior mediastinal surface in 9%. Five had associated cardiac injuries, from motorcycle or motor vehicle accidents, and all died. In six patients, the heart herniated through the pleuropericardial laceration. Baumgartel [*20*] described a pericardial laceration caused by a rib fracture in a 33-year-old injured in a high speed MVA. In Parmley and associates' [*5*] series of 546 autopsies there were 36 isolated pericardial ruptures.

Cardiopulmonary resuscitation (CPR) is known to cause a variety of cardiovascular injury in adults. In Powner's [*22*] study of 70 patients who underwent autopsy after having had CPR, 19% had fractured ribs, 17% had bone marrow emboli, 9% had a fractured sternum, and 4% had mediastinal hemorrhage. Fractured ribs from CPR may perforate the heart [*23–25*], and excessive vigor in performing CPR has been blamed for a rupture of the interventricular septum [*26*] and right ventricle [*23*]. Elevated right ventricular pressure from a pulmonary embolus combined with CPR caused right ventricular rupture [*23*]. Pre-existing weakness (thinning from tricuspid regurgitation and granulomatous myocarditis) contributed to right atrial laceration in two cases [*27*].

Feldman and Brewer [*28*] found no CPR-induced rib fractures in 50 children. Of the children in their series who did have rib fractures half were caused by abuse, and the others by MVAs, rickets/osteoporosis, surgery, and osteogenesis imperfecta.

Reardon and colleagues [*29*] reported a case of a four-year-old with a right atrial rupture allegedly from CPR. The child was admitted to the hospital with a seizure, the cause of which could not be found. On the third hospital day, following an episode of hypotension, the child was found to have a pericardial tamponade. It was not until this time that the father "remembered" that he had performed CPR after the seizure had occurred. At surgery the child had a 2 cm laceration of the right atrium. Although the atrial laceration was reported as a complication of CPR, it is much more likely that the injury resulted from assault. The sequence of events are more likely to have begun with a blow to the chest causing the atrial laceration, followed by the seizure. It is also possible that there never was a seizure, that it was used as a reason for the father to have performed the "CPR." Supporting this theory is the fact that the father did not mention the CPR until after the tamponade was diagnosed and that a cause for the seizure was not found.

In summary, there is ample evidence that the six cases of cardiac laceration reported herein are assaultive. In four instances, there were multiple explanations given for the injury, and none were sufficient to explain the severity of the injury. The literature review has shown that, in general, a great amount of energy, approximating the force of a motor vehicle accident, is required to lacerate the heart. In some of the reported cases with seemingly minor trauma, other factors may have been important in causing the myocardial laceration. In two cases patients received localized impacts to the precordium; a bicycle handlebar [*16*] in one instance and a barbell [*19*] in the other. The type of surface (for example, smooth, or with projecting surfaces such as rocks) onto which the two patients fell [*7,8*] is not mentioned. The size of the child who jumped on the boy on the sled [*4*] is not given, nor is the part of the sled (corner or top) with which the victim's chest came into contact described.

In four of the children described in this paper, there were rib fractures and in each child there were at least two fractures. Other

TABLE 3—*Distribution of injuries by cardiac chamber—all ages.*

Author	# Patients	RA-%	RV-%	LA-%	LV-%	IVS-%	IAS-%	Mult-%
Fulda[a]	44	39	27	18	9			7
Baumgartel[a]	65	45	17	21	11			6
Bright[b]	152	23	20	20	24	7	1	9
Parmley[b]	353	12	19	7	17	8	7	30

[a] = clinical series; [b] = autopsy series; RA = right atrium; RV = right ventricle; LA = left atrium; LV = left ventricle; IVS = interventricular septum; IAS = interatrial septum; Mult = multiple chamber rupture.

studies have shown that rib fractures in children result from severe accidental or assaultive trauma, not from CPR. Although in our cases the right atrium was most commonly injured, our literature review showed that no one chamber is predisposed to rupture. The mechanism of rupture in our cases was either compression of the heart between the sternum and verteral column, or as indicated by the presence of the liver lacerations in 5 cases, a severe blow to the abdomen with transmission of the force via the inferior vena cava to the right side of the heart.

Cardiac lacerations in infants and young children result from severe blunt trauma such as occurs in motor vehicle accidents or in violent assaultive injury. This injury does not result from CPR or from minor accidents at home.

Acknowledgment

Thanks to Brian Simmons and Lois Huizenga for performing the literature search.

References

[1] Golladay, E. S., Donahoo, J. S., and Haller, J. A., "Special Problems of Cardiac Injuries in Infants and Children," *Journal of Trauma*, Vol. 19, No. 3, July 1979, pp. 526–531.

[2] Fulda, G., Brathwaite, C. E. M., Rodriguez, A., Turney, S. Z., Dunham, C. M., and Cowley, R. A., "Blunt Traumatic Rupture of the Heart and Pericardium: A Ten-year Experience (1979–1989)," *Journal of Trauma*, Vol. 31, No. 2, Feb. 1991, pp. 167–173.

[3] Bright, E. F. and Beck, C. S., "Nonpenetrating Wounds of the Heart. A Clinical and Experimental Study," *American Heart Journal*, Vol. 10, No. 3, Feb. 1935, pp. 293–321.

[4] Stein, W. and Revitch, E., "Traumatic Rupture of the Right Ventricle—An Unusual Case," *American Heart Journal*, Vol. 24, No. 5, Nov. 1942, pp. 703–705.

[5] Parmley, L. F., Manion, W. C., and Mattingly, T. W., "Nonpenetrating Traumatic Injury of the Heart," *Circulation*, Vol. 18, No. 3, Sept. 1958, pp. 371–396.

[6] Getz, B. S., Davies, E., Steinberg, S. M., Beaver, B. L., and Koenig, F. A., "Blunt Cardiac Trauma Resulting in Right Atrial Rupture," *Journal of the American Medical Association*, Vol. 255, No. 6, Feb. 14, 1986, pp. 761–763.

[7] Pollak, S. and Stellwag-Carion, C., "Delayed Cardiac Rupture Due to Blunt Chest Trauma," *American Journal of Forensic Medicine and Pathology*, Vol. 12, No. 2, June 1991, pp. 153–156.

[8] Jebara, V. A., Acar, C., Dervanian, P., Farge, A., Sousa Uva, M., Julia, P., Fabiani, N., Deloche, A., Blondeau, P., and Carpentier, A., "Traumatic Ventricular Septal Defects. Report of 3 Cases With Tricuspid Valve Rupture in 2 Cases," *Journal of Cardiovascular Surgery*, Vol. 33, March–April 1992, pp. 253–255.

[9] Knapp, J. F., Sharma, V., Wasserman, G., Hoover, C. J., and Walsh, I., "Ventricular Septal Defect Following Blunt Chest Trauma in Childhood: A Case Report," *Pediatric Emergency Care*, Vol. 2, No. 4, December 1986, pp. 242–243.

[10] Viano, D. C., King, A. I., Melvin, J. W., and Weber, K., Injury Biomechanics Research: An Essential Element in the Prevention of Trauma, *Journal of Biomechanics*, Vol. 22, No. 5, 1989, pp. 403–417.

[11] Mozzetti, M. D., Devin, J. V., Susselman, M. S., Lammert, G. R., and Olshaker, J. S., "A Pediatric Survivor of Left Ventricular Rupture After Blunt Chest Trauma," *Annals of Emergency Medicine*, Vol. 19, No. 4, April 1990, pp. 386–389.

[12] Dieter, R. A. III and Anderson, A. E., "Ventricular Septal Defect Caused by Nonpenetrating Trauma in a 3-year Old Child: Use of Extracorporeal Membrane Oxygenation in Preoperative Stabilization," *Journal of the Tennessee Medical Association*, Vol. 84, No. 10, Oct. 1991, pp. 492–493.

[13] Merzel, D. I., Stirling, M. C., and Custer, J. R., "Massive Fatal Ventricular Septal Defect Due to Nonpenetrating Chest Trauma in a Six-Year-Old Boy: The Role of Early Invasive Monitoring in an Evolving Lesion," *Pediatric Emergency Care*, Vol. 1, No. 3, Sept. 1985, pp. 138–142.

[14] Cumberland, G. D., Riddick, L., and McConnell, C. F., "Intimal Tears of the Right Atrium of the Heart Due to Blunt Force Injuries to the Abdomen. Its Mechanism and Implications," *American Journal of Forensic Medicine and Pathology*, Vol. 12, No. 2, June 1991, pp. 102–104.

[15] Smith, D., Walker, D., and Sturridge, M., "Traumatic Left Ventricular Aneurysm in an 8-year-old Child," *British Heart Journal*, Vol. 45, No. 2, Feb. 1981, pp. 222–224.

[16] O'Reilly, R. J., Kazenelson, G., and Spellberg, R. D., "Traumatic Pseudoaneurysm of the Left Ventricle," *American Journal of Diseases of Children*, Vol. 120, No. 9, Sept. 1970, pp. 252–254.

[17] Rees, A., Symons, J., Joseph, M., and Lincoln, C., "Ventricular Septal Defect in a Battered Child," *British Medical Journal*, Vol. 1, No. 5948, Jan. 4, 1975, pp. 20–21.

[18] Rosenthal, A., Parisi, L. F., and Nadas, A. S., "Isolated Interventricular Septal Defect Due to Nonpenetrating Trauma. Report of a Case with Spontaneous Healing," *New England Journal of Medicine*, Vol. 283, No. 7, Aug. 13, 1970, pp. 338–341.

[19] George, D. H., Stakiw, K., and Wright, C. J., "Fatal Accident with Weight-lifting Equipment: Implications for Safety Standards," *Canadian Medical Association Journal*, Vol. 140, No. 8, April 15, 1989, pp. 925–926.

[20] Baumgartel, E. D., "Cardiac Rupture from Blunt Trauma with Atrial Septal Defect," *Archives of Surgery*, Vol. 127, No. 3, March 1992, pp. 347–348.

[21] Fulda, G., Rodriguez, A., Turney, S. Z., and Cowley, R. A., "Blunt Traumatic Pericardial Rupture. A Ten-Year Experience 1979 to 1989," *Journal of Cardiovascular Surgery*, Vol. 31, No. 4, July–Aug. 1990, pp. 525–530.

[22] Powner, D. J., Holcombe, P. A., and Mello, L. A., "Cardiopulmonary Resuscitation-Related Injuries," *Critical Care Medicine*, Vol. 12, No. 1, Jan. 1984, pp. 54–55.

[23] Bodily, K. and Fischer, R. P., "Aortic Rupture and Right Ventricular Rupture Induced By Closed Chest Cardiac Massage," *Minnesota Medicine*, Vol. 62, No. 4, April 1979, pp. 225–227.

[24] Agdal, N. and Jorgensen, T. G., "Penetrating Laceration of the Pericardium and Myocardium and Myocardial Rupture Following Closed Chest Cardiac Massage," *Acta Medica Scandinavia*, Vol. 194, No. 5, Nov. 1973, pp. 477–479.

[25] Noffsinger, A. E., Blisard, K. S., and Balko, M. G., "Cardiac Laceration and Pericardial Tamponade Due to Cardiopulmonary Resuscitation After Myocardial Infarction," *Journal of Forensic Sciences*, Vol. 36, No. 6, Nov. 1991, pp. 1760–1764.

[26] Engelman, R. M., Rousou, J. A., and Schweiger, M., "Traumatic Ventricular Septal Defect Following Closed-Chest Massage: A New Approach to Closure," *Annals of Thoracic Surgery*, Vol. 38, No. 5, Nov. 1984, pp. 529–532.

[27] Biggart, J. D. and McClure, J., "Right Atrial Laceration. Complication of External Cardiac Massage," *British Heart Journal*, Vol. 37, No. 6, June 1975, pp. 652–655.

[28] Feldman, K. W. and Brewer, D. K., "Child Abuse, Cardiopulmonary Resuscitation, and Rib Fractures," *Pediatrics*, Vol. 73, No. 3, March 1984, pp. 339–342.

[29] Reardon, M. J., Gross, D. M., Vallone, A. M., Weiland, A. P., and Walker, W. E., "Atrial Rupture in a Child from Cardiac Massage by His Parent," *Annals of Thoracic Surgery*, Vol. 43, No. 5, May 1987, pp. 557–558.

Address requests for reprints or additional information to
Stephen D. Cohle, M.D.
Blodgett Memorial Medical Center
1840 Wealthy St. SE
Grand Rapids, MI 49506