Two-Handed Cardiopulmonary Resuscitation Can Cause Rib Fractures in Infants

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Abstract: The discovery of acute rib fractures in deceased infants and young children can be unsettling. Although significant injuries may occur subsequent to resuscitative efforts in adults, it is well documented that such injuries are rare in much younger individuals. In particular, it is considered exceptional for rib fractures to follow cardiopulmonary resuscitation (CPR) on an infant; thus, some pathologists will consider such a discovery to be evidence of abuse. However, little is known about what, if any, injuries might occur subsequent to the delivery of "2-handed" CPR. Five unrelated, nonsequential cases of infant death are reported where multiple acute anterolateral rib arc fractures followed 2-handed CPR delivered by trained medical personnel.

Key Words: pediatric, infant, child, forensic, pathology, autopsy, resuscitation, CPR, injuries, rib fractures

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Individuals immersed in the practice of pediatric forensic pathology recognize it to be a subspecialty interest of great complexity. The old clinical adage "children are not just small adults" is as true in death investigation as on the hospital ward. For a variety of reasons, we have only recently started to discern the forensic differences between adults and children. For example, caregiver cardiopulmonary resuscitation (CPR) efforts have been offered as an explanation for numerous soft tissue, bony, and visceral injuries in young children—a possibility supported by a review of the adult literature,[1–11] but not supported by careful review of the pediatric forensic pathology literature.[12–18] Specifically, it is rare for infants to sustain rib fractures from resuscitative efforts. However, as pointed out by Matshes and Lew,[15] this observation is based upon data derived from studies of infants undergoing traditional "1-handed" CPR, and not the "2-handed" technique recently recommended for adoption in the United States.[19] As such, death investigators have been asked to proceed cautiously in cases where infants were found to have rib fractures following 2-handed CPR, as the mechanics of chest compression delivery are different.

Over a period of 6 months, the author (Matshes) investigated the deaths of 5 infants whose autopsies illustrated numerous rib fractures without other evidence of trauma. These fractures were investigated through standard autopsy, histologic, radiologic, and other methods, and thorough investigation of the circumstances of death, detailing resuscitative efforts in particular.

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MATERIALS AND METHODS

This nonconsecutive prospective case series includes data derived from 5 infant death investigations, which occurred over 6 months. Infants were included in the series if (1) they were known to have had resuscitative efforts including 2-handed chest compressions; (2) rib fractures were discovered at autopsy and if those fractures could not be explained through some other mechanism; and (3) a detailed history of the mechanics of chest compressions was available. Data were collected and stored in a Microsoft Access database. Routine photographs, radiographs and histologic preparations were obtained. Death investigation included interviews of all people involved in the resuscitative process.

RESULTS

Five infants aged between 1 month and 4 months (Table 1) met all of the inclusion criteria. In all cases, metabolic and related bone diseases were ruled out on the basis of a review of all clinical, radiologic, gross, and histologic data, and the results of metabolic screening studies.

Case 1

A 1.5-month-old previously healthy white female was found dead while cosleeping with her mother on a queen-sized mattress. The infant was found supine. The mother was awakened by a friend who entered the bedroom to find the infant wedged between the mother and the mother's arm, with dried bloody fluid having drained from the infant's mouth down along the mother's right arm and forearm. The mother could not estimate how long she had been sleeping. At the scene of death, numerous empty beer cans were located next to the mattress where the death occurred.

Autopsy demonstrated a normal infant with growth parameters appropriate for her age. Features of natural disease were absent. The only evidence of trauma was unilateral right fourth and fifth rib fractures through the anterolateral aspects of their arcs. These fractures were greenstick-type and nondisplaced, had intact overlying parietal pleura, and were associated with subtle subpleural ecchymoses. The fractures were not identified on primary or secondary (rescreen) review of postmortem radiographs. Histologic evaluation of both fractures confirmed acute fractures with erythrocyte extravasation, without features of healing.

Historical query revealed that Emergency Medical Services (EMS) personnel used both 1-handed and 2-handed CPR, and continued until the infant arrived at a local hospital where only 2-handed chest compressions were delivered.

The cause of death was classified as overlay, and the manner of death was classified as accident.

Case 2

A 2-month-old previously healthy white male was found dead in bed while cosleeping supine with his mother on a child-size twin mattress. In addition to the 2 human occupants, the bed also contained numerous fluffy adult-sized pillows, stuffed toys,

TABLE 1. Characteristics of 5 Cases of Infants With 2-Handed CPR-Related Rib Fractures

Age (mo)	Sex	Race	Cause of Death	Manner of Death	No. Rib Fractures	Location of Rib Fractures
1.5	F	White	Overlay	Accident	2	Anterolateral—(R) 4,5
2	M	White	Hypertrophic cardiomyopathy	Undetermined	4	Anterolateral—(L) 3,4,5,6
2	F	White	Undetermined	Undetermined	9	Anterolateral—(R) 2,3,4,5; (L) 2,3,4,5,6
3	M	Black	Probable mechanical asphyxia	Undetermined	6	Anterolateral—(R) 3,4,5; (L) 3,4,5
4	M	White	Unexpected infant death while co-sleeping	Undetermined	4	Anterolateral—(R) 3,4; (L) 3,4

CPR indicates cardiopulmonary resuscitation.

and blankets. The infant was found supine, and his face was reportedly unobstructed by any of the surrounding materials. The mother denied overlay. She claimed to have had a normal sleep that included routine waking to check on the infant. She denied recent consumption of alcohol, medications and drugs of abuse.

Autopsy demonstrated a male infant with generalized somatic edema most notably around the eyes, in the soft tissues of the back, as well as the hands and feet. A 1 cm diameter ecchymosis was in the right occipital scalp without associated subgaleal ecchymosis, skull fracture, intracranial hemorrhages, or cerebrocortical contusions. The obviously enlarged heart weighed 43 g (expected weight 23 g[20]). The left ventricular walls and the interventricular septum were markedly thickened, and the subaortic region of the left ventricular outflow tract was narrowed to approximately 1 mm diameter. The lungs, liver, and spleen were all prominently congested.

The left third through sixth ribs had fractures along the anterolateral aspects of their arcs (Fig. 1). These fractures were transection type, were minimally displaced, had intact overlying parietal pleura, and were associated with only subtle subpleural ecchymoses (Fig. 2). The fractures were not identified on primary or secondary (rescreen) review of postmortem radiographs. Histologic evaluation of all 4 fracture sites confirmed the acute nature of the fractures with erythrocyte extravasation, without features of healing (Fig. 3).

Historical query revealed that upon discovering her infant unresponsive, the mother called 911, and with direction from Emergency Personnel, commenced traditional 1-handed CPR. Upon arrival of EMS, 2-handed CPR was commenced, and continued until the infant arrived at a children's hospital, where resuscitative efforts were terminated.

The cause of death was classified as hypertrophic cardiomyopathy. The contribution of the unsafe sleep circumstances to death was speculative, and the manner of death was certified as undetermined (in accordance with the philosophies of the office in which the autopsy was conducted).

Case 3

A 2-month-old previously healthy white female was found dead while sleeping supine in a proper crib at daycare, secured in place by a snug blanket, in the absence of a pillow, toys, or other extraneous materials. The infant was reportedly bottle fed and put to bed. She was discovered dead by the daycare operator. The older children in the daycare reportedly did not have access to the infant.

Autopsy demonstrated a normal infant with growth parameters appropriate for her age. Features of natural disease were absent. The only evidence of trauma was bilateral second through fifth fractures, and a left sixth fracture, all through the anterolateral aspects of the rib arcs. These fractures were transection-type, were minimally displaced, had intact overlying parietal pleura, and were associated with only subtle subpleural ecchymoses. The fractures were not identified on primary or secondary (rescreen) review of postmortem radiographs. Histologic evaluation of all 9 fractures confirmed acute fractures with erythrocyte extravasation, without features of healing.

Historical query revealed that upon discovery that the infant was unresponsive, the day care operator called 911 and commenced classic 1-hand, 2-finger chest compressions. Upon arrival

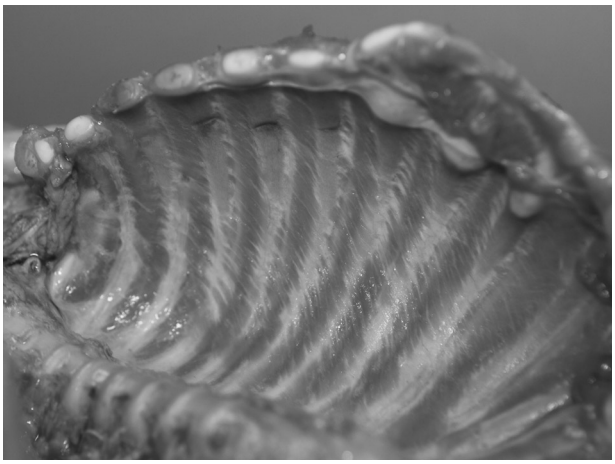

FIGURE 1. Left rib cage from Case 2. Acute anterolateral arc fractures of the left third through sixth ribs. The parietal pleura has been removed.

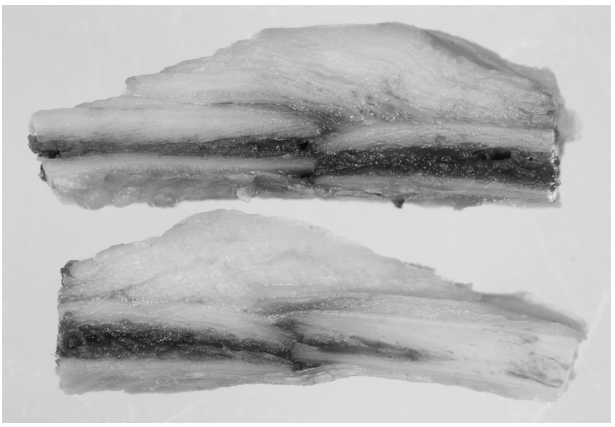

FIGURE 2. Cut section of transection-type left fourth rib fracture from Case 2, taken parallel to the rib plane.

FIGURE 3. Low-power microscopic view of rib fracture illustrated in Figure 2 (H & E 2X). Note that there is no inflammation, proliferative or reactive periosteal changes, prominent subperiosteal or intramedullary hemorrhage, intramedullary fibrin, necrotic bone fragments, or cartilage and new bone formation.

of EMS, 2-handed CPR was used and continued until the infant arrived at the local hospital, where resuscitative efforts were terminated.

The cause and manner of death were certified as undetermined.

Case 4

A 3-month-old black male was found dead on an adult queen-sized mattress, prone, with a blanket partially covering his head and face, and with an over-sized plush toy overtop his entire head and face.

Autopsy demonstrated a normal infant with growth parameters appropriate for his age. Features of natural disease were absent. The only evidence of trauma was bilateral third through fifth rib fractures through the anterolateral aspects of their arcs. These fractures were transection-type, were minimally displaced, had intact overlying parietal pleura, and were associated with only subtle subpleural ecchymoses. The fractures were not identified on primary evaluation of postmortem radiographs, and could only be suggested with hindsight on secondary (rescreen) evaluation of the radiographs. Histologic evaluation of all 6 fractures confirmed acute fractures with erythrocyte extravasation, without features of healing.

Historical query revealed that upon discovering her infant unresponsive, the mother called 911, and with direction from Emergency Personnel, commenced traditional 1-handed CPR. Upon arrival of EMS, 2-handed CPR was commenced, and continued until the infant arrived at a children's hospital, where resuscitative efforts were terminated.

The cause of death was classified as mechanical asphyxia, and the manner of death was classified as accident.

Case 5

A 4-month-old white male was found dead while cosleeping with his mother on a queen-sized mattress. The infant was found supine, and his face was reportedly unobstructed by any of the surrounding materials. The mother denied overlay. She claimed to have had a normal sleep over a period of 4 hours. She denied recent consumption of alcohol, medications, and drugs of abuse.

Autopsy demonstrated a normal infant with growth parameters appropriate for his age. Features of natural disease were absent. The only evidence of trauma was bilateral third and fourth rib fractures through the anterolateral aspects of their arcs. These fractures were transection type, were minimally displaced, had intact overlying parietal pleura, and were associated with only subtle subpleural ecchymoses. The fractures were not identified on primary or secondary (rescreen) review of postmortem radiographs. Histologic evaluation of all 4 fractures confirmed acute fractures with erythrocyte extravasation, without features of healing.

Historical query revealed that upon discovery that the infant was unresponsive, the mother called 911 and then called the grandmother (a trained neonatal intensive care nurse) from the next room. The grandmother commenced 2-handed CPR. Upon arrival of EMS, both 1-handed and 2-handed CPR was used, and continued until the infant arrived at a children's hospital, where resuscitative efforts were terminated.

The cause of death was classified as unexpected infant death while cosleeping, and the manner of death was classified as undetermined.

DISCUSSION

Errors in pediatric death investigation may have severe consequences.[21] Over- interpretation or erroneous interpretation of findings can lead to inappropriate cause and manner of death classifications. Thus, accurate death investigation demands answers for all injuries discovered in infants and young children. In the context of resuscitation, infantile rib fractures, especially when occurring in multiplicity, are decidedly uncommon.[15] Thus, the discovery of one or more fractures demands close scrutiny. In these 5 cases, otherwise atraumatic infants were discovered to have rib fractures without apparent explanation. Through careful investigation, the most likely culprit was identified to be chest compressions delivered during resuscitative efforts. Given the low likelihood that multiple fractures would follow traditional (1-handed) CPR, the logical conclusion is that in the absence of other causative factors, these rib fractures were caused by the application of 2-handed CPR.

FIGURE 4. One-handed, 2-finger CPR. The downward forces are directed at approximately the midsternum. The infant will be lying supine on a supportive surface.

FIGURE 5. Two-handed, 2-thumb CPR. The downward forces are directed at approximately the midsternum. The remaining fingers wrap around the chest and act as a brace. The infant will be lying supine on a supportive surface.

Literature regarding "typical" abuse-related rib fractures abounds—posterior, paravertebral and rib head fractures are considered particularly ominous.[12,14,22–25] The 5 cases presented in this article were strikingly similar in the number and distribution of fractures. In 3 cases, the fractures were bilateral. Fractures always involved the fourth rib, and neighboring ribs. Fractures were always multiple. All fractures were in the anterolateral aspects of the rib arcs. Fractures of the posterior rib segments were not identified. In 4 cases, the fractures were transection type, but minimally displaced. In 1 case, the fractures were incomplete (greenstick). The overlying parietal pleura was always intact, and all cases had only subtle subpleural ecchymoses.

One-handed and 2-handed CPR both involve the delivery of similar forces to the midchest (Figs. 4 and 5). However, by using 2 thumbs on the sternum, and the remaining 8 fingers on the back (as a brace) more impressive forces are generated, and

FIGURE 6. Impressive, symmetric chest compressions can occur with the 2-handed, 2-thumb technique.

FIGURE 7. Anterior compression of the chest can be quite significant with the 2-handed, 2-thumb technique. Posterior chest compression is not a significant factor with this technique.

thus, more dynamic chest compressions (Figs. 6 and 7).[26] Although one might suppose that abusive infantile torso squeezing (such as might be seen if an infant is shaken) and 2-handed CPR involve identical motions, simple experimentation with a doll will demonstrate the difference (Figs. 8 and 9). In 2-handed CPR, the second through fifth fingers are used as a simple brace while the thumbs deliver force to the central chest. In cases of chest squeezing or violent shaking, the thumbs might compress the anterior chest while the remaining fingers apply significant forces to the posterior rib elements. It is for this reason that posterior rib fractures are felt to be highly suggestive of inflicted injury, and not the consequence of resuscitative efforts, even with 2-handed CPR.

One limitation of this study appears to be our lack of data regarding the duration of individual applied CPR methodologies, the relative mix of 1-handed and 2-handed CPR techniques, and quantitative data regarding the degree of applied force. Unfortunately, obtaining even semi-accurate data about any of these 3 elements is virtually impossible for a number of factors including the drama that frequently surrounds "pediatric code calls." However, regarding the degree of applied force, it is safe to assume that trained EMS technicians and physicians

FIGURE 8. When an infant is deliberately squeezed or violently shaken, similar forces could be delivered to the midchest. However, the infant would not be lying on a supportive surface, and rather than acting as a mere brace wrapped around the chest, the fingers would be compressing the back and applying force directly to the ribs.

FIGURE 9. Posterior chest compression can be quite significant when an infant is deliberately squeezed or violently shaken. Fractures of the posterior rib elements typify inflicted injuries of this variety.

would report performing CPR with enough vigor to promote circulation.

CONCLUSION

Although infantile rib fractures from traditional 1-handed CPR are rare, the same cannot be said of 2-handed CPR. In this short case series, the fractures were in the anterolateral arcs of the third through sixth ribs, and in 2 cases, were symmetric bilaterally. None of the cases had associated cutaneous abrasions or soft tissue ecchymoses, nor were there injuries of thoracoabdominal organs. In all 5 cases, thorough investigation with directed questioning disclosed that 2-handed CPR was performed on the infants. Investigation, a detailed autopsy and ancillary studies allowed investigators to conclude that the fractures were immediately perimortem or postmortem, were unrelated to the cause of death, did not occur in the background of metabolic or other bone diseases, and were unlikely to have been intentionally inflicted (ie, abusive in nature). Although rib fractures are alarming, and potentially sinister in nature, investigators must be cautioned to thoroughly investigate the nature of rib fractures through all available means, including interviews with emergency medical personnel detailing chest compression technique.

The 2-handed resuscitation technique on infants may result in rib fractures. The fractures are possibly a manifestation of incorrect manual chest compression technique, overly zealous responders and/or a combination of additional factors. These fractures were not accompanied by any other injuries to the chest or abdomen, and should not be interpreted as the cause of death but as findings secondary to CPR. Remember that an infant requiring CPR may have multiple intentionally inflicted injuries, including rib fractures. Nevertheless, this apparent association between the 2-handed chest compression technique and discovery of rib fractures in infants undergoing such resuscitation creates an opportunity for evaluation and refinement of the technique, and confirms the value of proper CPR training for medical and nonmedical personnel.

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