Cardiopulmonary Resuscitation
Injuries in Children

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Abstract

Cardiopulmonary resuscitation (CPR) is an emergency intervention to maintain circulation and breathing in an unresponsive individual suffering from cardiopulmonary arrest. However, CPR is not without its own risks. Injuries secondary to compression and ventilation are well documented in the medical and scientific literature. Most of these injuries are minor, but some can result in significant morbidity and even death. It is important to identify those injuries that could be secondary to CPR versus inflicted traumatic injuries of child maltreatment.

Introduction

Besides medical personnel, members of the general public have been trained to perform CPR. Manual external CPR involves chest compressions at a rate of...
at least 100 per minute for all age groups, at a depth of at least 5 cm in adults, and
at least 1/3 of the depth of the anteroposterior chest diameter in infants and
children below the age of puberty. Often a child is brought to the attention of
a health-care professional or death investigator, and the etiology of injuries, in
particular CPR versus inflicted blunt force trauma, becomes a crucial issue. Perpe-
trators may claim that injuries were caused by CPR, either by themselves or by
emergency personnel. It is important to understand those injuries known to be
secondary to CPR in order to better identify and classify inflicted injuries of child
maltreatment.

**Resuscitation Injuries**

Injuries secondary to CPR are usually pathophysiologically insignificant (Bush et al.
1996; Plunkett 2006; Matshes and Lew 2010a; Ryan et al. 2006; Matshes and Lew
2010b; Reyes et al. 2011). Such injuries may be external and/or internal. It is best to
divide the injuries into categories: head and neck, thorax and abdomen, barotrauma,
and iatrogenic artifacts. Most CPR injuries involve the head/neck and rarely the
thorax and abdomen. These injuries are due to the compressions and to ventilation/
intubation. One should be aware of the resuscitative technique used on children and
note if the resuscitator is experienced in this technique (Reyes et al. 2011). The
techniques include one-handed compressions (“two finger”), two-handed compres-
sions (“two-thumb-encircling hands”), and abdominal compressions. The emer-
gency medical services (EMS) personnel or physician can easily demonstrate how
he/she performed CPR. The investigator can correlate injuries with points of
contact during compressions and ventilation. A doll can be used as well as the
same type and size of mask. If available, the exact mask used during the resusci-
tation should be retained. It must be noted that some studies of many resuscitated
children report no injuries. In other studies, injuries were noted, but none were
significant or abdominal (Matshes and Lew 2010a, b; Price et al. 2000; Feldman
and Brewer 1984).

1. **Head and Neck:** Most CPR-related injuries in children are soft tissue injuries of
the head and neck from ventilatory efforts (Kaplan and Fossum 1994). These include facial abrasions (nasal bridge, undersurface of the nose, anterior
chin) from the air-bag-valve mask, which are usually symmetrical. As the
resuscitator positions his/her hand on the child, fingertip contusions beneath
the chin and on the side of the head may be produced. If a mask is not used but
instead mouth-to-mouth, one may see scrapes/fingernail scratches over the
perinasal area.

Intubation can result in abrasions and/or contusions of the oropharynx, gingiva, buccal mucosa, frenulum, epiglottis, base of the tongue, larynx, and
trachea. The lips may be contused or lacerated from the victim’s own teeth or by
the endotracheal tube (Fig. 14.1). Teeth can also be broken during intubation.
The child’s oropharynx is more susceptible to damage by forceful digital
clearing and suction as well as by endoscopic instruments (Figs. 14.2, 14.3). Traumatic mucosal tears and hypopharyngeal perforation have occurred and are not uncommon (Galvis and Kelley 1979).

2. Thorax and Abdomen: Chest compressions can result in midsternal abrasions and/or slight contusions. Epicardial hematoma, pleural petechiae or ecchymosis,
and pulmonary interstitial hemorrhage can also occur (Bush et al. 1996; Matshes and Lew 2010b; Price et al. 2000) (Fig. 14.4a–c). Rib fractures secondary to CPR are rarely reported and are more often the result of inflicted trauma (Bush et al. 1996; Gunther et al. 2000; Spevak et al. 1994; Maguire et al. 2006; Dolínak 2007). Rib fractures are discussed further in the latter portion of this chapter.

Although extremely rare, compressions in children may result in pancreatic hemorrhage, hepatic/splenic contusion or laceration, retroperitoneal hemorrhage, and gastric perforation (Bush et al. 1996; Ryan et al. 2006; Waldman et al. 1984; Custer et al. 1987; Krischer et al. 1987). Note if abdominal compressions were performed (Waldman et al. 1984).

3. **Barotrauma**: Various forms of CPR-related barotrauma have been described in children (Cullen 2001). These include tympanic membrane injury, pneumothorax, pneumoperitoneum, pneumoscrotum, and air embolism (especially in the premature newborn) (Bush et al. 1996). Less commonly, gastric rupture (usually lesser curvature) due to overdistension during ventilation may result.

4. **Artifacts/Iatrogenic Marks Other than from Compression/Ventilation**: Artifacts include defibrillator marks over the thorax, venipuncture and intrasosseous line access marks, bruising about the neck from attempted vascular access, and adhesive marks from taping the endotracheal tube. Defibrillation can produce subepicardial myofibril disintegration. One can also see cardiac contraction band necrosis and focal hemorrhage with the administration of catecholamines during prolonged resuscitation.

### Issues Often Raised Concerning CPR

- **Retinal Hemorrhages (RHs)**: Previous studies and collaborative research have concluded that CPR alone does not cause retinal hemorrhages in children with normal coagulation and platelet count (Odom et al. 1997). In patients with nontraumatic illnesses and coagulopathies, small, punctate retinal hemorrhages...
may be present (Odom et al. 1997). Infants found unresponsive invariably undergo resuscitative efforts, often for prolonged periods of time. Forensic pathologists must be aware that retinal hemorrhages can be seen in infants who die suddenly and unexpectedly, following cardiopulmonary resuscitation, and are not specific for abusive head trauma. Infants found unresponsive without evidence of head trauma or natural disease processes that have had CPR,
especially those with restoration of circulation, can have RHs that may be few in number or numerous with extension to the ora serrata (Fig. 14.5a–d) (Tatum et al. 2012).

• **Visceral Injuries**: Several studies report no visceral injuries to children secondary to CPR (Matsches and Lew 2010a, b; Price et al. 2000; Feldman and Brewer 1984; Cohle et al. 1995). Others report that, if present, these CPR-related injuries are not significant or life-threatening (Matsches and Lew 2010b). Abdominal visceral injury is uncommon (Price et al. 2000); however, if present, note if abdominal compressions were performed (Waldman et al. 1984).

• **Rib Fractures**: Unlike adults, ribs in children are flexible and more resilient to fracture. In the absence of radiographic evidence of underlying bone disorder, unexplained rib fractures are indicative of abuse. Often rib fractures are associated with other signs of abuse and/or different stages of healing. However, recent studies using axial radiography have shown rib head fractures related to CPR, especially using the two-handed “two thumbs encircling hands” technique.
Length of compression time does not appear to correlate with an increased chance of rib fractures. Below is a more in-depth discussion of this challenging area in differentiating rib fracture from resuscitation versus inflicted trauma.

**Rib Fractures**

Current recommendations by the American Heart Association place emphasis on high-quality chest compressions (Field et al. 2010). The two acceptable techniques for chest compressions in infants are the use of either the first and second fingers on one hand or the two-handed technique. Since 2006, the preferred technique for chest compressions is two-handed, with the thumbs generating pressure on the sternum and the second through fifth fingers offering light support on the back (Kattwinkel 2006) (Fig. 14.6).

Reports of CPR in adults suggest fractures of the ribs occur at an incidence of 20–65 %, but such injuries are reportedly rarely seen in children (Ryan et al. 2006; Feldman and Brewer 1984; Krischer et al. 1987; Powner et al. 1984). Prior to the introduction of the preferred two-handed compression technique in 2006, there were only three reported cases of resuscitation-related injuries in children (Maguire et al. 2006). Compared to an adult, the rib cage of a child has greater elasticity and plasticity due to incomplete bone development and therefore may be able to tolerate larger degrees of pressure before a fracture occurs.

Rib fractures found in children with no clinical history of trauma or underlying bone disorders are most often associated with child abuse, accounting for 5–27 % of all skeletal injuries in abused children (Barsness et al. 2003; Platt et al. 2006). Most abusive rib fractures are believed to occur from anteroposterior compression, with the hands wrapped around the infant’s chest, produced by excessive squeezing or indirectly generated by shaking. Although abusive compression can cause anterolateral rib fractures, it has been attributed to injuries of the posterior ribs near the costovertebral junction and may involve the rib head, rib neck, and posterior rib arc. The compressive force levers the posterior ribs over the transverse processes of the spine (Kleinman and Schlesinger 1997; Bulloch et al. 2000). Since one-handed CPR is typically performed with the child on a firm surface, this posterior levering should not occur.

When rib fractures are present in an infant who has received CPR, the forensic pathologist must take care to distinguish abusive fractures from those that are related to resuscitative efforts. This is especially true with the two-handed technique, given that significant anterior compression may be produced (Matshe and Lew 2010a; Reyes et al. 2011). Resuscitation-related rib fractures are usually located either anteriorly or anterolaterally and are often multiple, linear, bilateral, or symmetrical (Fig. 14.7). These fractures usually occur near ribs 4 and 5 but have also been reported in ribs 2 through 9, the clavicle, and the sternochondral junction (Bush et al. 1996; Betz and Liebhardt 1994). If resuscitative efforts are unsuccessful, CPR-induced posterior rib fractures often have minimal associated hemorrhage and may be difficult to identify unless the parietal pleura has been reflected (Fig. 14.8).
**Fig. 14.6** Anterior-posterior radiograph taken while two-handed compression technique was performed in the neonatal intensive care unit (NICU) on a 10-week-old infant. A 2-year-old with a history of upper respiratory infection positive for coronavirus was found unresponsive. He was resuscitated for 40 min and survived 24 h. No injuries were identified.

**Fig. 14.7** (a) Fractures of left anterior ribs 2–6 with intact pleura in a 10-week-old infant following CPR. (b) Fractures of right anterior ribs 3–5 in a 5-week-old who died suddenly and unexpectedly. (c) Left anterior rib fracture shown with pleura stripped in a 3-month-old after 20 min of CPR.
Autopsy

To detect and confirm the presence of rib fractures at autopsy, a radiologic skeletal survey consisting of full-body, anteroposterior radiographs should always be performed prior to beginning the autopsy. Fresh rib fractures may be missed by radiography, but can be detected at autopsy by stripping the parietal pleura from the thorax and carefully examining each rib by visual inspection and manual palpation. Often the rib fractures will be subtle, bending or buckle fractures, with little or no associated hemorrhage. Microscopic examination of resuscitation-related fractures should show no surrounding tissue reaction with minimal associated extravasated blood histologically (Dolinak 2007; Weber et al. 2009).

Conclusion

Although usually pathologically insignificant, injuries secondary to CPR do occur and must be distinguished from inflicted injuries of child maltreatment. The investigator must be aware of common injuries of CPR and how these may differ from abusive trauma. Knowledge of the type of resuscitation, mask, and intubation
instruments used is needed to assess any injuries that may be identified. Doll reenactment may be useful during the investigation. Special attention should be paid to bony fractures and visceral injury as these are not commonly identified as secondary to CPR. Also, any remote injuries should raise suspicion. A complete autopsy preceded by radiologic skeletal survey should be performed.

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