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Cardiopulmonary resuscitation (CPR)-related posterior rib fractures in neonates and infants following recommended changes in CPR techniques☆

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ABSTRACT

Posterior rib fractures are highly indicative of non-accidental trauma (NAT) in infants. Since 2000, the "two-thumbs" technique for cardiopulmonary resuscitation (CPR) of newborns and infants has been recommended by the American Heart Association (AHA). This technique is similar to the grip on an infant's thorax while shaking. Is it possible that posterior rib fractures in newborns and infants could be caused by the "two-thumbs" technique? Using computerized databases from three German children's hospitals, we identified all infants less than 12 months old who underwent professional CPR within a 10-year period. We included all infants with anterior–posterior chest radiographs taken after CPR. Exclusion criteria were sternotomy, osteopenia, various other bone diseases and NAT. The radiographs were independently reviewed by the Chief of Pediatric Radiology (MB) and a Senior Pediatrician, Head of the local Child Protection Team (IF). Eighty infants with 546 chest radiographs were identified, and 50 of those infants underwent CPR immediately after birth. Data concerning the length of CPR was available for 41 infants. The mean length of CPR was 11 min (range: 1–180 min, median: 3 min). On average, there were seven radiographs per infant. A total of 39 infants had a follow-up radiograph after at least 10 days. No rib fracture was visible on any chest X-ray. The results of this study suggest rib fracture after the use of the "two-thumbs" CPR technique is uncommon. Thus, there should be careful consideration of abuse when these fractures are identified, regardless of whether CPR was performed and what technique used. The discovery of rib fractures in an infant who has undergone CPR without underlying bone disease or major trauma warrants a full child protection investigation.

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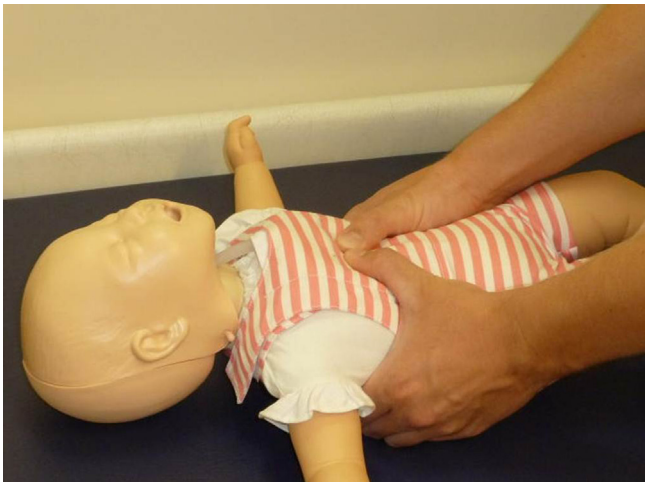

Fig. 1. Two-thumbs encircling-hands chest compression.

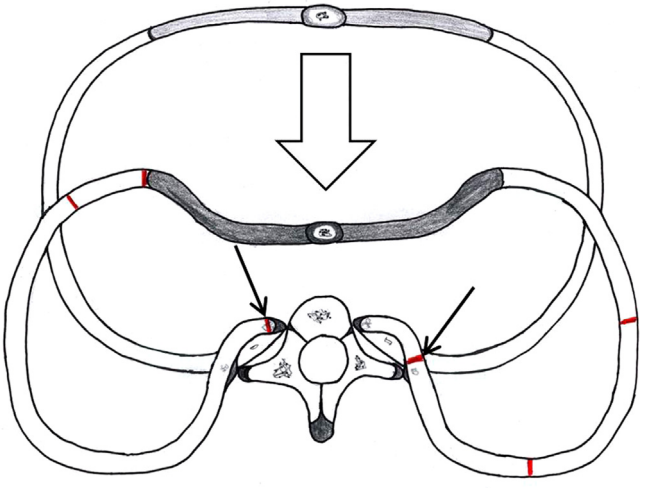

Fig. 2. Mechanism of posterior rib fracture. Anterior–posterior compression of the rib cage leads to leverage of posterior ribs over the vertebral transverse process, which causes tension in the inner aspect of the rib head or neck, resulting in fractures (black arrows). Fractures caused by compression can also occur at other sites of the rib (red marks) (according to Kleinman, 2005). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Introduction

Since 2000, the new "two-thumbs" technique has been recommended by the American Heart Association, in collaboration with the International Liaison Committee on Resuscitation, as the preferred technique for cardiopulmonary resuscitation (CPR) of newborns and infants (AHA, 2000).

The "two-thumbs" technique may generate higher arterial and coronary perfusion pressures than the traditional "two-fingers" technique (AHA, 2000; ERC, 2002; Houri, Frank, Menegazzi, & Taylor, 1997). When performing the "two-thumbs" technique, both hands encircle the infant's chest while the thumbs perform compressions of the middle to lower third of the sternum (Fig. 1) (AHA, 2000; ERC, 2002).

Any rib fracture in a newborn or infant is highly concerning and suggests abuse (Agran et al., 2003; Cadzow & Armstrong, 2000; Day, Clegg, McPhillips, & Mok, 2006; Kemp et al., 2008; Kleinman & Schlesinger, 1997; Leventhal, Martin, & Asnes, 2008; Offiah, van Rijn, Perez-Rossello, & Kleinman, 2009), and posterior rib fractures are especially specific (Day et al., 2006; Kleinman, 2005; Mulpuri, Slobogean, & Tredwell, 2010). The infant's rib cage is not easily fractured, and fractures are not observed following ordinary household trauma falls (Kleinman & Schlesinger, 1997; Kleinman, 2005). Furthermore, there are only a few accidental occurrences leading to the specific mechanism that causes posterior rib fractures (Herrmann, Dettmeyer, Banaschak, & Theyen, 2008, chap. 2.3.2, 5.7.2; Kleinman & Schlesinger, 1997; Kleinman, 2005). This mechanism involves the leverage of the posterior ribs against the vertebral transverse process due to anterior–posterior compression of the rib cage (Fig. 2) (Herrmann et al., 2008; Kleinman & Schlesinger, 1997; Kleinman, 2005; Worn & Jones, 2007). When rib

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fractures occur in an otherwise healthy infant without underlying bone disease or a plausible history of a severe accident with anterior–posterior compression of the chest, NAT should be suspected. Barsness et al. (2003) reviewed the medical records and imaging of 78 children and found that rib fractures were positive predictors of NAT in 95% of cases.

Rib fractures are often hidden and difficult to detect (Bulloch et al., 2000; Kleinman et al., 2002; Mulpuri et al., 2010). In the case of suspected abuse, a skeletal survey is the method of choice in children less than three years old. The skeletal survey utilizes an anterior–posterior chest X-ray to detect posterior rib fractures (AAP, 2009). Repeating the X-ray after at least 10 days is useful because the initiation of callus formation causes increased sensitivity for the detection of rib fractures (Anilkumar, Fender, Broderick, Somers, & Halliday, 2006, Kleinman et al., 1996; Klotzbach, Delling, Richter, Sperhake, & Püschel, 2003; Offiah et al., 2009). It has been discussed whether more images of the chest, such as lateral and oblique imaging, would allow for better detection of rib fractures (Kemp et al., 2006; Wootton-Gorges et al., 2008). Radionuclide imaging is sensitive to subtle acute rib fractures and may increase their detection rate (Herrmann et al., 2008; Mandelstam, Cook, Fitzgerald, & Ditchfield, 2003; Offiah et al., 2009). Entire body imaging, also known as a 'baby gram', is insufficient and therefore obsolete (Herrmann et al., 2008; Kleinman et al., 1996).

Several studies indicate that CPR does not cause posterior rib fractures in healthy newborns and infants (without bone dysplasia or osteopenia) (Betz & Liebhardt, 1994; Bush, Jones, Cohle, & Johnson, 1996; Dolinak, 2007; Gunther, Symes, & Berryman, 2000; Hoke & Chamberlain, 2004; Matshes & Lew, 2010). The conclusions of these studies are based on the suppositions that the forces occurring during CPR are too weak to fracture the still elastic skeleton of the infant and that the infant is meant to lie on a firm surface so that the described leverage of the ribs cannot appear (in the case of the "two-fingers" technique).

After introducing the "two-thumbs" technique, which may increase the efficiency of CPR, the traditional opinion must be reviewed. Clouse and Lantz (2008) described four premature infants (1 day to 3 months old) who died after CPR (two-thumbs technique). Abuse was excluded in every case, though in the post-mortem examinations, posterior rib fractures were observed in all infants. Reyes, Somers, Taylor, and Chiasson (2011) reviewed autopsy reports of 571 resuscitated infants from 1997 to 2008. Anterior and lateral rib fractures occurred more frequently after 2005, and the rate of CPR-related rib fractures increased from 1.3% to 7.9%. Reyes et al. (2011) attributed the increased rate to the introduction of the "two-thumbs" technique in their clinic in 2005.

The purpose of the current study is to investigate the incidence of posterior rib fractures related to the "two-thumbs" technique in neonates and infants. If CPR-related rib fractures do occur, it will be essential to clarify whether these rib fractures differ from NAT-associated rib fractures.

Methods

Using data taken from a 10-year period (2001–2010), we reviewed the medical records of newborns and infants who underwent CPR in their first year of life in three German hospitals (Department of Pediatrics, University of Bonn; Department of Pediatrics, Clinic of Nuremberg; Department of Pediatrics, University of Düsseldorf). The records were found via systematic search of the hospitals' patient archives. IRB approval was obtained. The data extracted from the individual patient charts included age; sex; birth history; gestational age; complications during pregnancy and birth; type of birth; age at CPR; length of CPR; diagnoses and history of diseases and operations by the time of CPR; any evidence of skeletal disorders; and type and number of X-rays.

We included all infants with anterior–posterior chest radiographs after CPR. Only anterior–posterior chest X-rays were conducted. Oblique views, post-mortem images and autopsies were not available. After reviewing the medical records to eliminate those infants with the exclusion criteria, 80 patients were accepted into the study. The following patient flow diagram illustrates the process of data collection and the inclusion and exclusion criteria (Fig. 3).

Every radiograph was independently reviewed by the Chief of Pediatric Radiology and a Senior Pediatrician, Head of the Bonn Child Protection Team, with 20 years of expertise. Evaluations of conventional X-rays were carried out on a Planilux® Gerätebau Felix Schulte, Warstein, Germany light box (model: DX 140 cm × 43 cm/EHR-AP; density: 2000–5600 cd/m^2) and blended with continuously adjustable light intensity (model: IRIS 100® Planilux Irisleuchte IRIS 100, Siemens Healthcare Diagnostics GmbH, Eschborn, Germany, density: 52.300 cd/m^2). Digital X-rays were examined on a screen (screen for appraisal based on DIN V 6868-57 and QS–guideline) from AGFA Health Care®.

All X-rays were examined, and particular attention was paid to rib fractures. Each X-ray was evaluated for two characteristics: any signs of rib fractures (pos/neg) and X-ray quality (1 = good delineation of the ribs; 2 = moderate delineation of the ribs; 3 = limited delineation of the ribs).

On the basis of these criteria, each case was divided into one of the following categories:

1 = no rib fracture detected, and follow-up is available;
2 = no rib fracture detected, and follow-up is not available;
3 = rib fracture cannot be excluded (e.g., because of limited quality of the X-ray);
4 = suspected rib fracture, and no follow-up to confirm suspicion;
5 = definite rib fracture.

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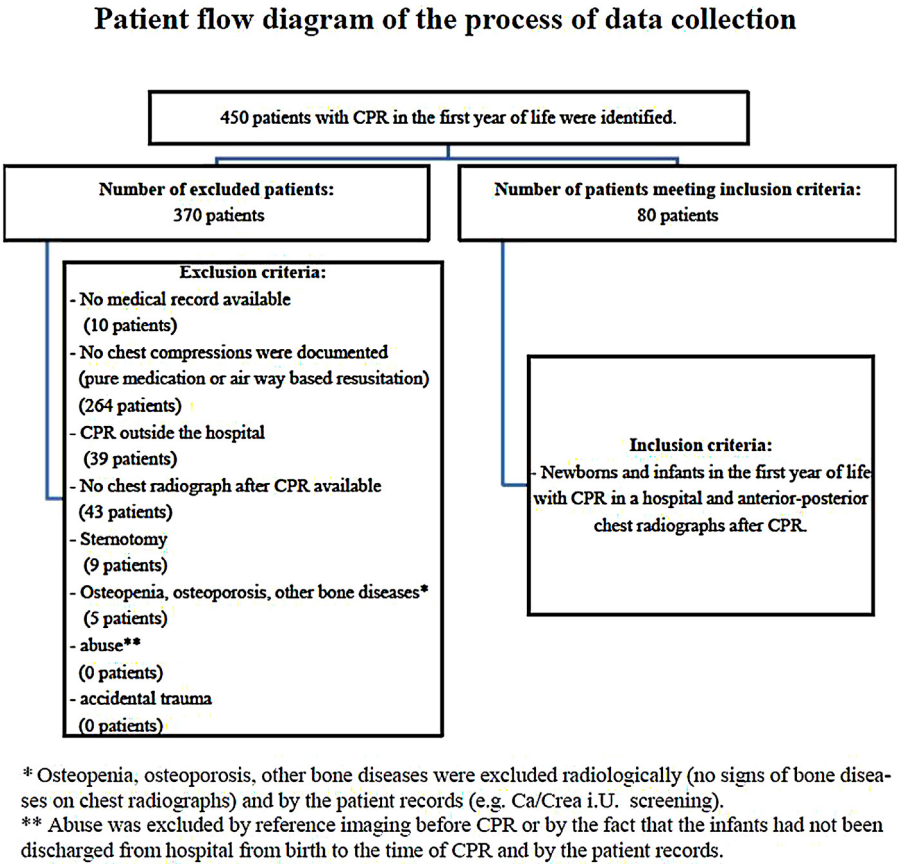

Fig. 3. Patient flow diagram of the data collection process (2001–2010) and illustration of the inclusion and exclusion criteria.

Analysis of the data was performed using Excel 2010 and IBM SPSS Statistics 21. We used the Kappa test to express the inter-rater reliability of the examiners and Fisher's exact test to compare the quality of the conventional and digital radiographs. To estimate the probability of rib fracture, we used Hanley's rule and the 2-sided 95% confidence interval (CI).

Results

Eighty infants (from 0 days to 11 months old) with 546 chest radiographs were identified. Of these infants, 27 (33.7%) were female, and 53 (66.3%) were male. Forty-nine (61.2%) infants were premature, eight (10.0%) had a very low birth weight (<1500 g, VLBW) and 23 (28.8%) had an extremely low birth weight (<1000 g, ELBW). Fifty infants (62.5%) underwent CPR immediately after birth. The length of CPR was noted in only 44 medical records (51.8%). The mean length of CPR was 11 min (range: 1–180 min, median: 3 min). In 27 cases (33.8%), the length of CPR was 5 min or less. The patient characteristics are summarized in Table 1.

On average, there were seven radiographs per infant (range: 1–30 radiographs, median: 4.5 radiographs), and 39 infants (48.8%) had a follow-up radiograph after at least 10 days. The following table illustrates a general view of the number of radiographs per infant (Table 2).

Table 1
Patient characteristics.

Patients (*n*)	80
Age at CPR (days)	9 (1–331)
Male/female	53/27
Birth weight (g)	2072 (308–4970)
Premature	49
VLBL (<1500 g)	8
ELBW (<1000 g)	23
CPR (min)	11 (1–180)

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Table 2
Number of radiographs per infant. 39 infants (48.8%) had a follow-up radiograph after at least 10 days. 47 infants (58.8%) had more than 3 radiographs.

	Number of infants	Number of radiographs	Number of infants with follow up (>10 d)
1 radiograph/infant	13	13	0
2 radiographs/infant	11	22	2
3 radiographs/infant	9	27	4
>3 radiographs/infant	47	484	33
Total	80	546	39

X-rays of 20 infants (25%) were taken using digital imaging systems, and 60 infants (75%) had conventional radiographs. Fisher's Exact Statistics were performed to compare the quality of the conventional and digital radiographs based on the rating of the examiners. For this analysis, the mean value of the two examiners' results concerning the quality of the X-rays was calculated (1–3 X-rays per infant). No significant correlation was found between the quality of the X-rays and the radiographic technique.

All 546 radiographs were checked for rib fractures and were independently rated for quality by the two examiners.

For comparability reasons, the three qualitatively best X-rays for each patient were selected for statistical analysis. Forty-seven infants (58.8%) had more than 3 radiographs; thus, a selection was possible for these infants. In total, 203 of the 546 X-rays were used for statistical analysis. Delineation of the ribs was good in 154 of the 203 radiographs (76.6%) (examiner 1: 82.8%; examiner 2: 69.5%). In 49 of the 203 X-rays (23.4%), delineation of the ribs was limited (examiner 1: 17.2%; examiner 2: 30.5%), meaning the radiographs had many artifacts or parts of ribs were poorly or not visible. Using the Kappa coefficient, inter-observer reliability of the two examiners was calculated. The strength of agreement between the two examiners was good (Kappa = 0.78) (Altman, 1999). Inter-observer reliability was highest in category 1 (no rib fracture detected; follow up is available).

Fig. 4 illustrates the examiners' division based on the evaluation of the X-rays for rib fractures. No rib fracture was found in any infant. In 41 infants (51.2%), rib fractures could not definitively be excluded because of the limited quality of the X-rays or unavailable follow-up radiographs.

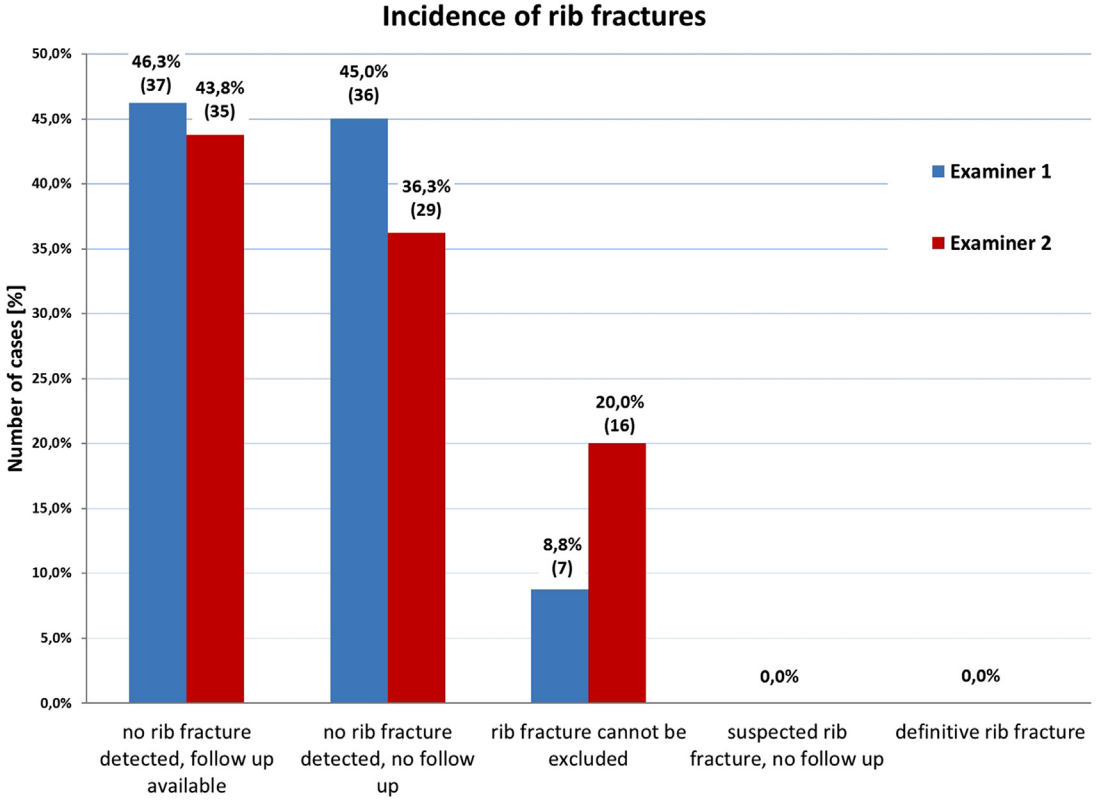

Fig. 4. Results of the evaluation of X-rays for rib fractures. No rib fracture was found in any infant. In 12 infants (14.4%), rib fractures could not definitively be excluded because of the limited quality of the radiographs.

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Limitations

Limitations of this study include the retrospective design, limited sensitivity of radiologic diagnostics and the small cohort.

Due to the retrospective analysis of the medical records, some information could not be obtained. After 2000, the "two-thumbs" technique was taught and used as the preferred CPR technique in the three hospitals included in this study. However, the type of CPR was not noted in the medical records, so it is possible that the CPR technique may have varied between the CPR providers, thus limiting generalizability.

The length of CPR was noted in 44 medical records (51.8%), and the length of CPR was less than 5 min in 29 patients (34.1%). The length of CPR could be a factor for the occurrence of CPR-associated rib fractures. However, this correlation is not supported in the literature; Reyes et al. (2011) suggests no correlation between the length of CPR and the occurrence of rib fractures.

In this study, 49 infants (61.2%) were premature, eight (10.0%) had a very low birth weight (<1500 g, VLBW) and 23 (28.8%) had an extremely low birth weight (<1000 g, ELBW). Production and mineralization of bone tissue has been shown to exponentially increase during the third trimester of pregnancy (Lucas-Herald et al., 2012). Consequently, prematurity leads to a higher risk of osteopenia. In our cohort, all patients underwent weekly urine screening. The incidence of prematurity-associated osteopenia in VLBW infants varies from 10 to 30% (Amir et al., 1988; Dabezies & Warren, 1997; Johnson, 1991; Koo et al., 1989; Lucas-Herald et al., 2012; Miller, 2003). The rate of VLBW-related posterior rib fractures is stated to be 0–1.8% (Amir et al., 1988; Lucas-Herald et al., 2012; Smurthwaite, Wright, Russell, Emmerson, & Mughal, 2009). In the current study, neither references in the patients' medical records nor radiological signs for osteopenia were observed. Even with the probable increased risk of fractures in premature infants, no CPR-related rib fractures were found in this study.

Concerning the study design, X-rays are not optimal for detecting rib fractures because they were made for different purposes (e.g., to determine the correct position of a central vein catheter). This limitation could decrease the sensitivity of the X-rays. At a minimum, the radiographic technique (kV, mAs) would be similar.

Only anterior–posterior imaging was conducted. Oblique views, post-mortem images and autopsies were not available, which could decrease the sensitivity of radiological diagnostics.

The sensitivity of chest X-rays for detecting acute rib fractures is 47–59% (Cattaneo et al., 2006; Klotzbach et al., 2003). A follow-up chest X-ray increases sensitivity (Anilkumar et al., 2006; Harlan, Nixon, Campbell, Hansen, & Prince, 2009; Kleinman et al., 1996; Zimmerman, Makoroff, Care, Thomas, & Shapiro, 2005). In 5 of 59 children (9%) less than 2 years old, additional rib fractures were identified in follow-up chest radiographs (Anilkumar et al., 2006). In this study, 39 infants (48.8%) had follow-up visits after at least 10 days. In 41 infants (51.2%), rib fractures could not be definitively excluded due to the lack of appropriate follow-up radiographs or the limited quality of the radiographs.

Because there were no confirmed or suspected rib fractures detected in this study (0 events), we used Hanley's rule to state the estimate (Hanley & Lippman-Hand, 1983) and the two-sided 95% confidence interval (CI). With 95% confidence, the maximum risk of rib fractures after CPR in infants is estimated to be no greater than 3.8% ($3/n = 3/80 = 3.8\%$), with a 4.5% CI. With a group of 80 infants and a power of 0.8, the rate of CPR-related rib fractures would be 13.9%, which significantly differs from the literature rate of between 0 and 2%. When considering only the 39 patients with follow-up radiographs, the maximum risk of rib fractures after CPR is estimated at 7.7%, with a 9% CI. Consequently, the study result does not significantly differ from the rate of CPR-related rib fractures given in literature.

Discussion

While CPR-related rib fractures in adults are commonly reported in the literature (incidence: 12.9–96.6%), the rate of CPR-related rib fractures in infants is stated between 0 and 2% (Betz & Liebhardt, 1994; Bulloch et al., 2000; Bush et al., 1996; Cadzow & Armstrong, 2000; Dolinak, 2007; Feldman & Brewer, 1984; Gunther et al., 2000; Hoke & Chamberlain, 2004; Maguire et al., 2006; Matshes & Lew, 2010; Offiah et al., 2009; Reyes et al., 2011; Spevak, Kleinman, Belanger, Primack, & Richmond, 1994; Weber, Risdon, Offiah, Malone, & Sebire, 2009). The listed studies have different study designs and are greatly heterogeneous concerning case numbers, mean age and imaging methods. In studies before 2000, the authors refer to the "two-fingers" technique or do not distinguish between the two techniques (Betz & Liebhardt, 1994; Bulloch et al., 2000; Bush et al., 1996; Cadzow & Armstrong, 2000; Dolinak, 2007; Feldman & Brewer, 1984; Gunther et al., 2000; Hoke & Chamberlain, 2004; Maguire et al., 2006; Matshes & Lew, 2010; Offiah et al., 2009; Spevak et al., 1994; Weber et al., 2009).

After the introduction of the "two-thumbs" technique, it is uncertain whether CPR can cause posterior rib fractures in infants. In a rabbit study, Kleinman and Schlesinger (1997) showed that posterior rib fractures do not occur following sternal compressions on a firm surface (as in "two-fingers" technique), but do occur following manual anterior–posterior compression with posterior migration of the rib arc (as in "two-thumbs" technique). While case reports have suggested that the "two-thumbs" technique can cause posterior rib fractures (Clouse & Lantz, 2008), the likelihood of fractures after the "two-thumbs" technique CPR is unknown.

This problem has great relevance in the legal trackback of NAT. Without clarification, the occurrence of rib fractures after unexplained cardiac arrest leading to subsequent CPR leads to a diagnostic dilemma. Cases are described in the literature where the plea was based on a desperate CPR attempt (Gunther et al., 2000; Kleinman, Blackbourne, Marks, Karellas, &

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Belanger, 1989). However, there have been abuse convictions based on a child's unusual trauma constellations partly caused by CPR (Plunkett, 2006). These case reports confirm the importance of clarifying the problem.

The results of this study suggest that any type of rib fracture after the "two-thumbs" CPR technique is uncommon. While performing the "two-thumbs" technique, aids may try to create a base with their fingers, which could prevent the leverage of the ribs.

Reyes et al. (2011) found an increased rate of anterior and lateral rib fractures in a review of autopsy protocols after 2005. They did not find any posterior rib fractures (Reyes et al., 2011). These authors attributed their findings to the introduction of the "two-thumbs" technique in their clinic and explained these results by noting an increased indentation depth while performing the "two-thumbs" technique compared to the "two-fingers" technique.

However, these findings cannot be confirmed through the current study because no anterior or lateral rib fractures were found. As Reyes et al. (2011) included a larger cohort and used a more sensitive diagnostic method in their study, it could be possible that the results would change with increasing cohort size.

In this study, all CPR was performed by medical professionals. Some studies suggest more CPR-associated injuries occur when performed by professionals compared to untrained individuals (Betz & Liebhardt, 1994). These authors suggest that untrained individuals are afraid to cause greater injuries (Betz & Liebhardt, 1994). Even with an assumed greater propensity to injuries or fractures, no CPR-related rib fracture was found in this study.

Conclusion

Occurrences of posterior rib fractures are highly significant for both diagnostic investigation and legal trackback of NAT. Exclusion of CPR as a cause of posterior rib fractures in newborns and infants increases the diagnostic accuracy of NAT. The results of this study suggest that any rib fracture is uncommon after the "two-thumbs" CPR technique. There should be careful consideration of abuse when these fractures are identified, regardless of whether CPR was performed and which technique was applied.

Conflicts of interest

All authors declare no conflicts of interest.

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