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Increased incidence of CPR-related rib fractures in infants—Is it related to changes in CPR technique?☆

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ABSTRACT

Objective: A recent increase in the number of infants presenting at autopsy with rib fractures associated with cardio-pulmonary resuscitation (CPR) precipitated a study to determine whether such a phenomenon was related to recent revision of paediatric resuscitation guidelines.
Methods: We conducted a review of autopsy reports from 1997 to 2008 on 571 infants who had CPR performed prior to death.
Results: Analysis of the study population revealed CPR-related rib fractures in 19 infants (3.3%), 14 of whom died in the 2006–2008 period. The difference in annual frequency of CPR-related fractures between the periods before and after revision of paediatric CPR guidelines was statistically highly significant.
Conclusions: The findings indicate that CPR-associated rib fractures have become more frequent in infants since changes in CPR techniques were introduced in 2005. This has important implications for both clinicians and pathologists in their assessment of rib fractures in this patient population.

1. Introduction

In the absence of an overt history of accidental trauma or disease-related bone fragility, rib fractures in the paediatric age group are considered to be virtually pathognomonic of inflicted injury.[1] In a recent study by Jayakumar et al.[2] isolated or multiple rib fractures, irrespective of location, were considered to have the highest specificity for non-accidental injury (NAI). Fractures in the paediatric age group are only very rarely attributed to cardio-pulmonary resuscitation (CPR).[3–5]

Every 5 years, the American Heart Association (AHA) convenes an international consensus conference to review CPR and emergency cardiovascular care guidelines. Through evidence-based assessment of current guidelines, evaluation of hypotheses and reviews of recent research this International Liaison Committee on Resuscitation (ILCOR) generates consensus statements and new treatment recommendations for basic life support (BLS), advanced cardiac life support (ACLS), paediatric advanced life support (PALS) and neonatal resuscitation.[6] In 2005 healthcare provider guidelines for paediatric CPR were modified with an increased emphasis on rigorous chest compressions.[7,8] When two healthcare providers are available the person compressing the chest can use the recommended "two-thumbs encircling hands" (TT) technique as it has been shown in previous studies to produce higher coronary perfusion pressures and more consistently correct depth and force of compression than the "two-finger" (TF) technique.[9–14] The objective is to depress the infant's chest by 1/3 to 1/2 the depth of the chest at a rate of 100 compressions per minute ("push hard, push fast") allowing full chest recoil after each one while minimizing interruptions.

The revised CPR practice was adopted at the Hospital for Sick Children ahead of its official publication at the end of 2005. Since mid-2006, we have noted a striking increase in the frequency of acute rib fractures attributable to CPR in our infant autopsy population, particularly those less than 6 months of age. A study was therefore undertaken to confirm this impression and to assess how this increased frequency of CPR-related rib fractures might correlate with institution of revised CPR recommendations.

2. Methods

The Division of Pathology at the Hospital for Sick Children performs paediatric autopsies under both next-of-kin consent and pursuant to Coroner's warrants. Following research ethics board approval, all autopsy files from 1997 to 2008, inclusive, were reviewed to identify all cases with rib fractures attributable to CPR;

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Table 1
Infants aged ≤6 months who underwent CPR during the study period: 1997–2008, inclusive ($N = 571$). Numbers in bold: data used to calculate P value from Fisher's exact test.

	CPR-related rib fractures	No CPR-related rib fractures	Totals
1997–2005 (pre-CPR revision period)	**5**	**389**	394
2006–2008 (post-CPR revision period)	**14**	**163**	177
Totals	19	552	571

establish its annual frequency; and document the number and location of the rib fractures. A diagnosis of CPR related rib fractures was based on: characteristic location of the fractures (anterior, antero-lateral and/or lateral rib segments); acute nature, usually with limited periosteal haemorrhage and with no histological evidence of a cellular inflammatory response; and exclusion of other potential causes for rib fractures (e.g. MVAs, falls, etc.). These criteria are similar to data previously reported about CPR-related rib fractures.[3–5] Rib fracture data was correlated with patient demographics; nature and duration of CPR; post-mortem radiological findings; cause of death; and other major pathological findings.

3. Results

During the study period, 571 infants aged newborn to 6 months had resuscitative efforts performed prior to death (Table 1). Rib fractures were ascribed to CPR in 19 infants (3.3%): 11 females and 8 males, with age range from 0 to 179 days (mean – 78 days). All 14 infants who became unresponsive at home had CPR performed by EMS personnel. 5 infants were hospital in-patients. Aetiology of out-of-hospital cardiac arrest (OHCA) included natural diseases, infections, drowning and undetermined causes with the latter comprising the largest group.

All the fractures involved anterior to lateral rib segments and most frequently the 4th and 5th ribs. Rib fractures were radiologically diagnosed in only 4 of the 15 infants who had post-mortem diagnostic imaging performed. For the 16 patients in whom the duration of CPR was known, it ranged from 21 to 260 min (average – 64 min) (Table 2). The number of fractures per subject varied from 1 to 11 and did not correlate with the duration of CPR.

From 1997 to 2005 (pre-CPR revision period), there were a total of 5 CPR-related rib fracture cases. From 2006 to the end of 2008 (post-CPR revision period), there were 14 cases of CPR-related rib fractures (Fig. 1). The proportion of infants less than 6 months of age with CPR-related rib fractures was statistically highly significant in the post-CPR revision group when compared to the pre-CPR revision group ($p < 0.001$, Fisher-exact test).

4. Discussion

The results of this study confirm that there has been a statistically significant increase in the incidence of rib fractures attributable to CPR in infants aged ≤6 months and that this change is temporally related to a revision of infant CPR guidelines published in 2005.

Our study population for OHCA is similar to that of previous studies on the epidemiology and outcomes of paediatric OHCA. Atkins et al.[15] found that during a 16-month study period, of 277 infants aged newborn to less than one year (range – 1–4 months; mean age – 3 months) who experienced an OHCA, no obvious cause of arrest was identified in 205 (74%). Two hundred and thirty-two (84%) of them received CPR from EMS prior to arrival at hospital with only 9 infants surviving to discharge. In-hospital cardiac arrest (IHCA) most commonly occurs in patients in the intensive care setting. Nadkarni et al.[16] published a report using data for paediatric IHCA from the AHA's multicenter National Registry of Cardiopulmonary Resuscitation (NRCPR) in which 65% occurred in the Intensive Care Unit, 14% occurred in a general paediatric ward and 13% in the Emergency Department.

4.1. Increased incidence of CPR-related rib fractures in infancy

There are several factors to consider in determining the possible cause or causes of the increased incidence of CPR-related rib fractures in infancy. One is whether the affected infants were more inherently susceptible to developing fractures due to an underlying bone disorder. There was however no evidence, either radiological or pathological, of any such underlying abnormality detected in any of these infants.

The 2005 guidelines advocate a rate of 100 compressions per minute ("push fast"): as the length of time CPR is administered increased so too would the number of chest compressions applied. Another consideration therefore is whether an increased number of compressions per attempted resuscitation led proportionately to a higher number of infants with CPR-related rib fractures. If this were true one would by extension expect that the number of CPR-related rib fractures per infant would correlate with the duration of resuscitation. Our data demonstrated no such correlation.

We believe that the technique by which chest compressions are administered is the most important consideration in evaluating why there has been an increase in the number of CPR-related rib fractures. According to revised infant CPR guidelines (2005) the two thumb (TT) method is preferred with effective chest compression (CC) achieved at a compression depth (CD) of 1/3 to 1/2 of the infant's AP diameter.[6] This is because TT can generate higher compression pressures in comparison to the two finger (TF) method[10] leading to higher arterial and coronary perfusion pressures[11] and thus better cardiac output.[17]

Since there is no published data on the optimal target depth of CC specific to children guidelines for paediatric CCs are based largely on extrapolation from adult data and consensus interpretation of the literature[18] and animal models.[19] A recent study by Braga et al. [18] using computed tomography (CT) estimated the optimal CPR CC depth in children. Compression sufficient to compress the chest to <10 mm of residual internal chest depth was defined as over-compression. It concluded that simulated CC targeting 1/3 AP diameter seemed radiographically appropriate for children aged 3 months to 8 years. Conversely those targeting 1/2 AP seemed too deep, resulting in residual internal chest depth of <10 mm for most patients of this age. A similar study for neonates aged 28 days or less by Meyer et al.[20] coupled the estimation of optimal CPR CC depth with a mathematical model that calculated the approximate ejection fraction (EF) for compression depths of 1/4, 1/3 and 1/2 the AP diameter. Compression inadequate to obtain a predicted 50% EF was defined as under-compression. They found that chest compression recommendations of 1/3 AP diameter should be more effective than a 1/4 AP compression depth and safer than a 1/2 AP compression depth.

The AP diameter of the infant manikin model used in Udassi et al.'s[21] study was 88 mm with a maximum achievable CD of 28 mm. Maximal compression would have allowed rescuers to achieve 1/3 of the AP diameter of the chest, which is the lower limit of adequate depth as recommended in the 2005 guidelines. In their study most of the medical personnel participants did not achieve even 1/3 of the AP diameter. The mean CD with two thumbs was actually 1/6 of the AP diameter and the mean CD with two fingers was 1/9. These findings were present in the first minute of CPR suggesting that it was not due to fatigue. Furthermore Udassi also

Table 2
Infants ≤6 months of age with CPR-related rib fractures: 1997–2008 (*N* = 19). *Abbreviations*: WGA = weeks gestational age; NA = not available; P = parent; EMS = emergency medical services; ED = emergency department.

Case no. (year)	Sex	Age (days)	CPR duration (min)	Administered CPR	COD	CPR-related rib fractures/case	Rib(s) involved
1 (1997)	F	41	21	EMS > ED	Undetermined	11	L 2–6, R 2–7
2 (1997)	F	57	NA	EMS > ED	Congenital heart disease	3	L 3–5
3 (1999)	F	34	NA	EMS > ED	Undetermined	4	L 2–5
4 (2001)	F	140	NA	EMS > ED	Congenital h earl disease	5	L 2, R 3–6
5 (2005)	M	63	50	EMS > ED	Undetermined	6	L 4–6, R 4–6
6 (2006)	F	121	25	EMS > ED	Undetermined	6	L 1–4, R 2–3
7 (2006)	F	82	45	Ward	Metabolic disorder	9	L 2–5, R 2–6
8 (2006)	F	48 (25 WGA)	147	Ward	Complications of prematurity	9	L 1–4, R 1–5
9 (2007)	M	0	25	Ward	Infection	1	R 5
10 (2007)	M	34	35	EMS > ED	Undetermined	6	L 4–6, R 4–6
11 (2007)	M	142	56	P>EMS>ED	Undetermined	6	L 4–5, R 3–6
12 (2007)	F	138 (32 WGA)	77	P>EMS>ED	Undetermined	1	L 5
13 (2007)	F	75	31	P>EMS>ED	Undetermined	2	R 3–4
14 (2007)	F	131	40	Ward	Congenital heart disease	7	L 3–5, R 2–5
15 (2007)	F	37	75	ED	Familial cardiomyopathy	8	L 3–6, R 3–6
16 (2008)	M	80	50	EMS>ED	Infection	5	L 3–5.R 3–4
17 (2008)	M	179	260	EMS > ED	Drowning	3	L 3–5
18 (2008)	M	44	50	P > EMS > ED	Undetermined	9	L 2–6, R 3–6
19 (2008)	M	47	40	EMS > ED	Undetermined	10	L 2–6, R 2–6

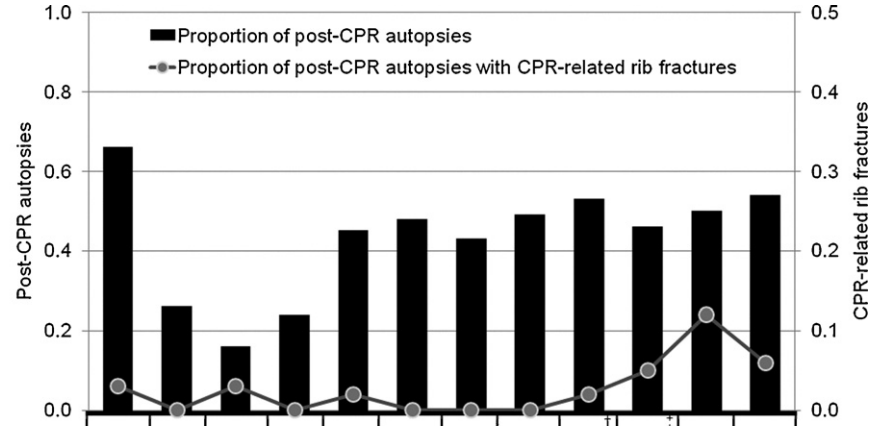
found that it is easier for rescuers to achieve higher compression depths using TT compared with TF.

We postulate that with the increased utilization of the TT method of chest compressions, CD's of greater than 1/3 the infant's AP diameter are more commonly achieved and that in a small number of infants the bending forces applied to the anterior to antero-lateral segments of the ribs is sufficient to result in fractures. Since this can occur at any point in time during resuscitative efforts it would explain why the number of rib fractures per subject neither correlated with the duration of CPR nor with the number of chest compressions applied.

4.2. Implications of our study

The significant increase in the number of CPR-related rib fractures in infants less than six months of age has important implications for both pathologists and clinicians. Foremost, it reinforces the notion that anterior to antero-lateral rib fractures in pre-mobile infants may be a result of CPR and are not pathognomonic of abuse.

Although the majority of research regarding paediatric CPR-related rib fractures has been conducted on non-survivors of cardiac arrest, some infants do survive. Several large studies in the United States and Canada on paediatric OHCAs demonstrated that survival to hospital discharge ranged from 2% to 8.6%.[15,22–27] For paediatric IHCAs the survival rate range is even higher, from 25% to 36%.[16,26–30] What is not known is the incidence of CPR-related rib fractures in these survivors. A recent study was conducted by Yan-Ren et al.[31] on post-resuscitative clinical features in the first hour after achieving sustained return of spontaneous circulation (ROSC) that predict the duration of survival in children with non-traumatic OHCA. Of the 80 children who achieved sustained ROSC, 15 had CPR-related rib fractures. Subsequently 13 of them died and they found that there was a statistically significant association between the presence of CPR-related rib fractures and not surviving to discharge. However, 2 children did survive despite having these injuries. It is therefore incumbent on both the clinician and the pathologist to bear in mind the possible role of CPR when assessing rib fractures in infants.



Cases	1997	1998	1999	2000	2001	2002	2003	2004	2005†	2006‡	2007	2008
CPR-related rib fractures	2	0	1	0	1	0	0	0	1	3	7	4
Total CPR	61	36	29	31	46	42	44	51	54	56	57	64

Fig. 1. Distribution of CPR-related rib fracture cases in infants ≤6 months. †Revised CPR guidelines published: December 2005. ‡First case of CPR-related rib fractures: May 31st, 2006.

5. Conclusion

In this study, we have demonstrated a significant increase in the incidence of resuscitation-associated rib fractures in infants after 2005, the year that CPR guidelines for infants were revised, advocating the "two-thumb encircling hands" technique for chest compressions with emphasis on a "push hard; push fast" approach.[6] Although a temporal association is evident, further study is needed to conclusively establish a causal relationship. Regardless of the reason for the increased incidence, the possibility of CPR-related rib fractures needs to be seriously considered in the evaluation of any infant presenting with rib fractures, when there is a history of CPR, so as not to misinterpret the finding as evidence of non-accidental/inflicted injury.

Conflict of interest statement

None to declare.

Contributors

All of the authors were involved in the conception and design of the study. JR was responsible for the acquisition of the data. JR, GS and DAC were involved in analysis and interpretation of the data; preparation and in critical revision of the manuscript. All of the authors approved the final version of the manuscript submitted for publication.

Ethical approval

Research Ethics Board, The Hospital for Sick Children.

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