Paediatric Traumatic Cardiac Arrest: A Delphi study to establish consensus on definition and management

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ABSTRACT

Aims

Paediatric traumatic cardiac arrest (TCA) is associated with low survival and poor outcomes. The mechanisms that underlie TCA are different from medical cardiac arrest; the approach to treatment of TCA may therefore also need to differ to optimise outcomes. The aim of this study was to explore the opinion of subject matter experts regarding the diagnosis and treatment of paediatric TCA, and to reach consensus on how best to manage this group of patients.

Methods

An online Delphi study was conducted over three rounds, with the aim of achieving consensus (defined as 70% agreement) on statements related to the diagnosis and management of paediatric TCA. Participants were invited from paediatric and adult emergency medicine, paediatric anaesthetics, paediatric ICU and paediatric surgery, as well as paediatric major trauma centre leads and representatives from the Resuscitation Council UK. Statements were informed by literature reviews and were based on elements of Advanced Paediatric Life Support resuscitation algorithms as well as some concepts used in the management of adult TCA; they ranged from confirmation of cardiac arrest to the indications for thoracotomy.

Results

73 experts completed all three rounds between June and November 2016. Consensus was reached on 14 statements regarding the diagnosis and management of paediatric TCA; oxygenation and ventilatory support, along with rapid volume replacement with warmed blood, improve survival. The duration of cardiac arrest and the lack of a response to intervention, along with cardiac standstill on ultrasound, help to guide the decision to terminate resuscitation.

Conclusion

This study has given a consensus-based framework to guide protocol development in the management of paediatric TCA, though further work is required in other key areas including its acceptability to clinicians.

[278 words]

INTRODUCTION

Trauma is the leading cause of death in children over one year of age.[1] Paediatric traumatic cardiac arrest (TCA) is associated with poor survival and poor neurological outcome. Reported outcomes, however, vary considerably, possibly owing to different definitions of TCA, mechanisms of trauma (some studies include drowning and electrocution) and pre-hospital factors, as well as differing healthcare environments and systems.

The underlying pathologies leading to cardiorespiratory arrest secondary to energy transfer or body cavity penetration in trauma are different from non-traumatic causes. These differences are being increasingly recognised in adult emergency medicine with many services adopting guidelines specific to the management of TCA.[2-5] Survival to discharge from hospital following adult TCA has improved in the last decade as interventions have targeted reversible causes, such as the early decompression of tension pneumothorax, correction of hypovolaemia from blood loss, and proactive management of acute traumatic coagulopathy.[6] Much of the data suggesting improved survival has come from military experience;[7] however this has now also been replicated in civilian populations.[8, 9]

A lack of consensus and guidance exists as to whether elements of the adult guidelines should be applied to children who experience TCA. Although more than 90% of injury deaths occur in low and middle-income countries, paediatric TCA is rare in the developed world, where emergency physicians will see only a small number of such presentations in their career.[9, 10] Clinical protocols and education may improve outcomes in such low frequency, high stress situations.

Delphi methodology, which is widely used to inform low frequency areas of practice such as this where alternative trial methodologies are unfeasible, was chosen to study paediatric TCA. The study aim was to explore the opinion of subject matter experts (SMEs) from the UK and Ireland regarding the diagnosis and treatment of paediatric TCA, and to reach consensus on how best to manage this group of patients.

METHODS

Consensus derivation methodology

A Delphi study,[11] comprising three rounds of questions, was undertaken between June and December 2016. Eligible participants were invited by an email that contained the background to the study, the need for engagement in up to three rounds, the likely time to complete each round, and a link to an online survey (SurveyMonkey®; SurveyMonkey Inc.; San Mateo, California, USA; www.surveymonkey.com). Each round was open for one month, and email reminders were sent two weeks, one week, and 48 hours before closing. Non-participation in any round precluded that participant from taking part in subsequent rounds, and no new participants were invited after completion of the first round.

Statements relating to assessment and management of paediatric TCA were presented for consideration; participants indicated their opinion on a five point Likert scale (strongly agree, agree, neutral, disagree, strongly disagree) and also had the option to provide free text answers. At the start of each round, participants were informed of the previous round's results by providing individual responses (including free text), as well as the overall quantitative response of the group (descriptive statistics illustrating the collective opinion).

Selection of survey content

To inform the Delphi process, available algorithms addressing the management of paediatric and adult TCA were interrogated by five of the authors (AR, JV, MDL, TN, JES).[5, 12] For each algorithm step a PICO format question was generated. A literature search was then undertaken for each of these,[13-16] and where evidence existed the question was removed from further study. Those questions for which no evidence existed were included in the first round of the online Delphi study.

This first round comprised 21 statements (Appendix 1). Free text responses from round one which related to terminology used, or strong repeated opinion were used to inform further statements for rounds two and three where necessary. Original questions were not altered in subsequent rounds, but statements which reached consensus were removed.

Participant and referee group selection

A number of stakeholder groups were identified, from which individuals with relevant expertise were identified and invited. Initial invitees were selected to ensure a degree of heterogeneity in disciplines, while guaranteeing input from those doctors most likely to see and lead the management of paediatric TCA in the UK and Ireland. First round participants were also invited to identify other potential participants to ensure the sample represented all relevant expert groups, and to reduce possible recruitment bias. Stakeholder groups comprised:

- Paediatric Emergency Research in the UK and Ireland (PERUKI)
- Paediatric Major Trauma Centres
- Paediatric Intensive Care Society (PICS)
- British Association of Paediatric Surgeons (BAPS)
- Association of Paediatric Emergency Medicine (APEM)
- Association of Paediatric Anaesthetists of Great Britain and Ireland (APAGBI)
- Faculty of Pre-Hospital Emergency Care
- Resuscitation Council UK (RC-UK)

Analysis

Consensus on each statement was set, *a priori*, at 70% agreement within each round, whether positive or negative, consistent with previous studies.[11, 17] Following each round, data were analysed anonymously. Responses were aggregated into three categories of "Agree" (agree/ strongly agree), "Neutral" and "Disagree" (disagree/ strongly disagree). For statements on which consensus was reached, median and interquartile range (IQR) scores were calculated from the five-point Likert scale results. For statements which did not reach consensus, medians and IQRs were used to demonstrate the spread of opinion in the responses.

Ethics

No formal research ethics approval was required for this study as it was a survey of health professionals identified via networks. Participation was deemed as consent.

RESULTS

91 participants of 108 invited (84%) completed round one; 66 of these 91 were identified via stakeholder groups, and 25 from participant suggestions. 83 of 91 (91.2%) completed round two and 73 of 83 (88%)

completed round three.

Specialties of the participants in round one are shown in Table 1. Three of the participants were higher specialty trainees (ST6 or greater); one core trainee participated, but only in round one; all other participants were consultants. Bracketed numbers indicate those who completed round three.

Of the 21 statements presented in round one, four reached consensus and were removed from further rounds. 14 new statements were added, resulting in 31 statements for round two. Six of these reached consensus and a further four were added for round three; four of the remaining statements reached consensus in the third round, leaving 25 statements which did not reach the preset level for consensus (Figure 1).

Of the statements that did reach consensus agreement, 12 reached positive consensus, and two reached negative consensus (Tables 2 and 3). Figure 2 shows the Delphi participant (Subject Matter Expert (SME)) flow through the study. The median score is 2 (equivalent to 'Agree') for all statements with positive consensus and 4 (equivalent to 'Disagree') for all statements with negative consensus, with an IQR of 0 or 1 for nearly all statements.

Agreement was reached that blunt and penetrating trauma should be treated differently, suggesting a need for two treatment algorithms. Agreement was also reached that absent palpable pulses, absent signs of life or no cardiac activity on ultrasound should define paediatric TCA.

Seven statements relating to specific interventions reached consensus. Participants agreed that oxygenation and ventilatory support should be provided in an attempt to improve survival, as should rapid volume replacement with warmed fluids (preferably blood). Whilst there was consensus that needle pericardiocentesis should not be done, participants supported the use of thoracotomy in penetrating trauma.

With regard to factors that help to define futility or when to stop resuscitation, consensus was reached on the duration of arrest, lack of response to intervention, and the presence of cardiac standstill on ultrasound.

For statements on which consensus was not reached (Table 3), percentages with predominantly positive, negative or Neutral/Don't know are indicated in bold. These percentages correspond with high median values (IQRs).

DISCUSSION

Through this Delphi study we have, for the first time, achieved consensus on 14 statements that inform the diagnosis and management of paediatric TCA. This consensus has drawn on the contribution of a large panel of experts from the UK and Ireland. Almost two-thirds of statements relating to key management steps did not achieve consensus, highlighting areas of persistent uncertainty.

In terms of the concept and definition of TCA, agreement was reached that blunt and penetrating trauma should be treated differently, suggesting a need for two treatment algorithms. Previously-published algorithms suggest that entry into a cardiac arrest algorithm (not specifically trauma) include: unresponsiveness to pain (coma), apnoea or gasping respiratory pattern, absent circulation and pallor or deep cyanosis. This study demonstrated agreement that absent palpable pulses, absent signs of life or no cardiac activity on ultrasound should trigger a paediatric TCA algorithm. This is in keeping with the current guidance from ILCOR.[18] In some circumstances paediatric TCA may represent a very low output state and not a true cardiac arrest, especially when it has a reversible cause.[19] This fundamental concept is why paediatric TCA should be approached differently to that of a medical cardiac arrest.

Seven statements relating to specific interventions reached consensus. Participants agreed that oxygenation and ventilatory support should be provided in an attempt to improve survival, as should rapid volume replacement with warmed fluids (preferably blood). These interventions aim to reverse hypoxia and hypovolaemia, and are given priority in existing treatment algorithms.[5, 20]

Whilst there was consensus that needle pericardiocentesis should not be done, participants supported the use of thoracotomy in penetrating trauma. The last two decades have seen a move away from pericardiocentesis in general, with some evidence that subxiphoid pericardiotomy is a more effective method to decompress haemopericardium in adults.[21] However, many favour thoracotomy in the context of TCA due to the likelihood of clotted blood within the pericardial sac.[18, 22] Previous work has advocated this approach in adults;[23] the consensus achieved in our study now suggests that this is viewed by experts as appropriate in children with penetrating trauma. Agreement was not reached on whether to undertake thoracotomy in blunt trauma for proximal haemorrhage control.

One of the greatest challenges of any paediatric cardiac arrest is knowing when to cease resuscitation. This decision is taken by clinicians in situations where survival is extremely unlikely, and although ROSC may be achieved, it is with a high likelihood of severe neurological impairment. In such cases there is a balance to be struck between futility or adverse outcome, and reversing potential causes of arrest while working with the family to do the best for the patient. A recent systematic review of paediatric cardiac arrest could draw no conclusions on the duration of resuscitation beyond which attempts would be futile or result in severe neurological impairment.[24] The recent ILCOR update[25] also reflects on the lack of evidence for intra-arrest prognostic factors across all causes of paediatric cardiac arrest. We reached consensus on a number of statements related to ceasing resuscitation efforts which relate to duration, response to interventions (including invasive procedures (see Appendix 1), and adjuncts for confirming cardiac standstill. However, while we anticipate that the statement "a lack of response to any intervention or invasive procedure is helpful in determining futility" can be used by clinicians involved in the management of paediatric TCA, other statements will require further clarification, using patient centred outcomes to guide study design.

While the use of point of care ultrasound may be helpful in determining standstill (and hence futility) after interventions, this is not currently available in all Emergency Departments in our healthcare system, although its use is increasing. The duration of cardiorespiratory arrest at which resuscitation attempts should be ceased remains elusive, and can only be answered fully by prospective collection of individualised data on national and international paediatric cardiac arrest registries. Until this becomes available, the decision to cease resuscitation will remain a judgment call for any resuscitation team and leader, which takes into account the nature and severity of the injuries, the completion of all interventions, and the ongoing absence of any signs of life.

From the statements that did not reach consensus, there was ongoing uncertainty about the appropriateness of external chest compressions and thoracostomy, dilemmas that were also reflected in the most recent ILCOR recommendations.

Of note from these results, a particular area of clinical uncertainty among participants concerned the use of vasopressors at and around the time of PTCA, as demonstrated by a median score of three (neutral/ don't know) in all causes, including those with severe brain injury. This suggests a need for experimental evidence and clinical trials in this area.

Limitations

The limitations of this study extend from the fact that, despite the introduction of modern trauma systems and Major Trauma Centres, paediatric TCA remains a rare and highly challenging situation for all involved, coupled with an extremely scant evidence base. It is unlikely that any one clinician in the civilian healthcare system will have personal experience of more than a handful of TCA events in children. There is therefore a danger of harnessing collective uncertainty from participants; however, in identifying key stakeholder groups, and accessing individuals with expertise through this route, we have minimised this and ensured as broad inclusion as possible. The integrity of the participants is revealed to a degree in the fact that two-thirds of statements did not reach consensus – a position which allows us to be more confident about those which did. This consensus study only included clinicians practicing in the UK & Ireland, and the findings may not be directly translatable to other healthcare settings given, for example, our low rates of gun crime. We did not actively involve members of the public in this consensus process, though we strongly believe that consultation with the public should take place in regards to any algorithm which may result for the management of paediatric TCA, given the graphic nature of some of the potentially life-saving interventions. In the wording of the statements written for this Delphi study, the phrase "improves outcome" was frequently used. Our participants commented not infrequently that there is no evidence of improved outcome regarding many of the topics we explored. This phrase, although intended to focus our thinking on patient centred outcomes, has inadvertently caused more hesitancy in many responses. This is a problem we did not anticipate at inception of the study, but may have hampered our ability to reach consensus in a few areas. REBOA and ECMO CPR (eCPR) were not covered in this Delphi study as these interventions were not commonly used in the UK and Ireland at the inception of the study. These may become part of future PTCA algorithms.

Finally, as only 14 statements reached consensus it was not possible to fully inform an algorithm for the management of paediatric TCA, although it is hoped this will be achieved through future work, including a face-to-face meeting of participants. However, the 14 statements which did reach consensus should be considered by all clinicians who may find themselves managing paediatric TCA.

CONCLUSION

This study has demonstrated consensus among a large panel of subject matter experts on several key elements of the diagnosis and management of children in TCA. Further work is required to establish a treatment algorithm based on evidence and consensus.

DECLARATION

The referee group and subject matter experts have no competing interests to declare and no material incentives were offered during this study.

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AR, TN and JS planned the study. Surveys were conducted and administered by JV and AR. DE analysed all of the data and reported this. Analysis and reporting of the work described in the article was done by AR, TN, ML, JS, DE, JV and IM. AR and JS submitted the article. AR and JS are responsible for the overall content as guarantors.

WHAT IS KNOWN ALREADY ON THIS SUBJECT?

Paediatric traumatic cardiac arrest (TCA) is associated with poor survival and poor neurological outcome.

Survival to discharge from hospital following adult TCA has improved in the last decade as interventions have targeted reversible causes, such as the early decompression of tension pneumothorax, correction of hypovolaemia from blood loss, and proactive management of acute traumatic coagulopathy.

A lack of consensus exists among clinicians as to whether elements of the adult guidelines should be applied to children who experience TCA.

WHAT THIS STUDY ADDS:

A three round Delphi study of experts in traumatic cardiac arrest in the UK and Ireland found consensus on several key elements of the diagnosis and management of children in TCA.

Consensus could not be achieved on the use of chest compressions in TCA, whether bilateral thoracostomies should be performed in all patients, or the use of vasopressors.

Further work is required to establish a treatment algorithm based on evidence and consensus.

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Table 1. Number and specialty of participants entering the study. Figures in brackets show those completing all three rounds.

Specialty	Number of participants
Paediatric EM (PEM)	44 (28)
EM (adult and paediatric)	28 (27)
Paediatric intensive care	11 (9)
Prehospital care	5 (5)
Paediatrics	0
Paediatric surgery	1 (1)
Paediatric anaesthesia	2 (2)

Table 2. Percentages of consensus and median (IQR) score for statements on which consensus was reached (based on ≥ 70% cut-off point). All statements were preceded by the phrase "In paediatric TCA…". * Median (Interquartile Range [IQR]) depends on a 5-point Likert scale, with 1= Strongly agree, 2= Agree, 3= Neutral/Don't know, 4= Disagree, 5= Strongly disagree. **Figure showing % agree/strongly agree for positive consensus, and % disagree/strongly disagree for negative consensus

	Round consensus reached	Number of respondents (% consensus)**	Median (IQR) score*
Concept/ Definition of paediatric TCA			
Blunt and penetrating trauma should be treated *differently**	Round 1	91 (72.5)	4 (1)
Absent palpable pulses or no signs of life should trigger a paediatric TCA algorithm	Round 2	82 (92.7)	2 (1)
The absence of cardiac activity on ultrasound should trigger a paediatric TCA algorithm	Round 2	80 (72.5)	2 (2)
Process			
Whole blood therapy improves survival	Round 1	90 (74.4)	2 (1)
Warmed blood/ fluids improves survival	Round 1	91 (72.5)	2 (1)
Rapid volume replacement improves survival	Round 3	73 (74.0)	2 (1)
Thoracotomy in penetrating trauma improves survival	Round 1	91 (72.5)	2 (1)
Pericardiocentesis should *not* be performed in paediatric TCA*	Round 3	73 (76.7)	4 (1)
Ensuring oxygenation (via an endotracheal tube or supraglottic device) improves survival	Round 2	83 (78.3)	2 (0)
Providing ventilatory support improves survival.	Round 3	73 (77.8)	2 (0)
Decision to stop			
Duration of arrest in paediatric TCA is helpful in determining the futility of continued resuscitation	Round 2	83 (84.3)	2 (0)
The lack of response to any intervention is helpful in	Round 2	83 (90.4)	2 (1)

determining the futility of continued resuscitation			
If all invasive procedures have been completed and there is no ROSC, this is helpful in determining the futility of continued resuscitation	Round 2	83 (95.2)	2 (1)
Cardiac standstill on ultrasound is helpful in determining the futility of continued resuscitation, in the presence of appropriate resources and a trained operator	Round 3	73 (72.6)	2 (1)

* These statements reached negative consensus – the statements used in the Delphi study were "blunt and penetrating trauma should be treated the same" and "pericardiocentesis is an essential procedure to perform in paediatric TCA".

Table 3. Percentages of consensus and median (IQR) score for statements on which consensus was not reached on round 3. * Median (Interquartile Range [IQR]) depends on a 5-point Likert scale, with 1= Strongly agree, 2= Agree, 3= Neutral/Don't know, 4= Disagree, 5= Strongly disagree.

	Number (percentage) of respondents			Median (IQR) score*
	Strongly agree/ Agree	Neutral/ Don't know	Strongly disagree/ Disagree	
Concept/ Definition of paediatric TCA				
Paediatric TCA should be treated in the same way with the same principles across the entire paediatric age range	47 (66.2)	6 (8.5)	18 (25.3)	2 (2)
Loss of heart sounds on auscultation should trigger a paediatric TCA algorithm	38 (52.1)	11 (15.1)	24 (32.9)	2 (2)
Process				
Performing chest compressions improves survival in patients where hypoxia is the likely cause of traumatic cardiac arrest	32 (44.4)	30 (41.7)	10 (13.9)	3 (1)
Delivery of chest compressions should be deprioritised compared with other life saving interventions	42 (57.5)	16 (21.9)	15 (20.6)	2 (1)
Measuring End Tidal CO_2 is helpful in determining the futility of continued resuscitation	45 (61.7)	22 (30.1)	6 (8.2)	2 (1)
Intubation improves survival	42 (58.3)	24 (33.3)	6 (8.3)	2 (1)
Performing bilateral thoracostomies improves survival	45 (61.6)	24 (32.9)	4 (5.5)	2 (1)
With a blunt mechanism of injury, the application of a pelvic binder improves survival	44 (60.3)	23 (31.5)	6 (8.2)	2 (1)
Paediatric TCA should be treated in the same way with the same principles regardless of the presenting cardiac rhythm	21 (29.2)	11 (15.3)	40 (55.5)	4 (2)
Shockable rhythms should be treated in the same way with the same principles as children in paediatric TCA who present with non-shockable rhythms	20 (28.2)	8 (11.3)	43 (60.5)	4 (2)
PTCA secondary to suspected isolated head trauma should be managed in the same way as all other paediatric TCA	19 (26.4)	5 (6.9)	48 (66.7)	4 (2)

Performing chest compressions improves survival in patients where hypovolaemia is the likely cause of paediatric TCA	16 (22.2)	24 (33.3)	32 (44.5)	3 (1)
In paediatric TCA due to BLUNT injury, thoracotomy improves survival	13 (18.1)	26 (36.1)	33 (45.8)	3 (1)
Performing chest compressions improves survival	24 (32.9)	34 (46.6)	15 (20.5)	3 (1)
Providing rescue breaths improves survival	32 (43.8)	30 (41.1)	11 (15.1)	3 (1)
Intubation with a cuffed endotracheal tube improves survival compared to intubation with an uncuffed endotracheal tube in patients aged 12 months or younger	10 (13.9)	48 (66.7)	14 (19.4)	3 (0)
Intubation with a cuffed endotracheal tube improves survival compared to intubation with an uncuffed endotracheal tube in patients aged over 12 months	21 (29.2)	39 (54.2)	12 (16.6)	3 (1)
The use of vasopressors at any time improves survival	5 (6.8)	39 (53.4)	29 (39.7)	3 (1)
The use of vasopressors at any time improves survival in patients sustaining isolated traumatic brain injury	17 (23.3)	41 (56.2)	15 (20.5)	3 (0)
The use of vasopressors at any time improves survival in patients with no evidence of traumatic brain injury	3 (4.1)	42 (57.5)	28 (38.4)	3 (1)
Having achieved ROSC following paediatric TCA, the use of vasopressors pre-surgery improves survival	18 (24.7)	45 (61.6)	10 (13.7)	3 (0.5)
Having achieved ROSC following paediatric TCA, the use of vasopressors pre-surgery improves survival in patients sustaining isolated traumatic brain injury	29 (40.3)	37 (51.4)	6 (8.3)	3 (1)
Having achieved ROSC following paediatric TCA, the use of vasopressors pre-surgery improves survival in patients with no evidence of traumatic brain injury	11 (15.1)	48 (65.7)	14 (19.2)	3 (0)
In paediatric TCA, due to BLUNT injury, thoracotomy for haemorrhage control improves survival	24 (32.9)	28 (38.3)	21 (28.8)	3 (2)

FIGURE LEGENDS

Figure 1. Flow of Statements through the Study.

Figure 2. Participant Flow through the Study.