Pediatric emergency resuscitative thoracotomy: A Western Trauma Association, Pediatric Trauma Society, and Eastern Association for the Surgery of Trauma collaborative critical decisions algorithm

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This is a recommended evaluation and management algorithm from the Western Trauma Association (WTA) Algorithms Committee in collaboration with the Pediatric Trauma Society (PTS) and the Eastern Association for the Surgery of Trauma (EAST). This work addresses the management of pediatric trauma patients who require emergency trauma evaluation and consideration of the performance of an emergency resuscitative thoracotomy (ERT). Because there are no published prospective randomized clinical trials on this topic that have generated Class I data, these recommendations are based primarily on in-depth review of published prospective and retrospective cohort studies, systematic reviews and meta-analyses, and expert opinion of the participating authors representing the WTA, EAST, and the PTS. The literature review included all references identified through a structured and in-depth initial literature search of the US National Library of Medicine and National Institutes of Health PubMed databases from 1975 through 2021, review of all identified abstracts, and selection of relevant abstracts for full text review. The full list of the 110 selected references from this search process is included as Supplemental Digital Content (Supplemental Digital Content 1, http://links.lww.com/TA/D90). The final algorithm is the result of an iterative process including an initial creation of a draft algorithm and supporting materials followed by internal review and revision by the WTA Algorithm Committee members, as well as the EAST and PTS coauthors. During this process, it was also felt that an accompanying ERT procedural guide flowchart would be useful to accompany the algorithm. The revised draft algorithm and accompanying procedural guide underwent a second round of internal review and revision, and then final revisions were based on input during and after presentation of the algorithm to the full WTA membership. An audio recording of the presentation of the Algorithm at the 2022 WTA Annual Meeting and the open question and answer period is included as Supplemental Digital Content (Supplemental Digital Content 2, http://links.lww.com/TA/D91).

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The development of the algorithm and manuscript follows (where applicable) the international Appraisal of Guidelines, Research and Evaluation recommendations and checklist (Supplemental Digital Content 3, http://links.lww.com/TA/D92).[1]

Emergency resuscitative thoracotomy (ERT) is a highly invasive procedure that is widely used in select trauma patients with profound and refractory shock not responsive to initial resuscitation or for those who present with or develop traumatic arrest. The procedure and associated outcomes have been well described in adult trauma patients, with survival rates ranging widely (0–80%) based on the injury mechanism and the timing of arrest.[2,3] In 2015, an EAST Practice Management Guideline on ERT in adult patients was published that included data from over 10,000 patients and provided evidence-based recommendations broken down by injury mechanism and patient physiology.[4] In addition, there are two previously published WTA algorithms that provide guidance on this topic, one specifically on adult ERT and one on the management of penetrating thoracic trauma in adults.[5,6] In contrast to the adult population, there is significantly less experience and published literature for ERT in pediatric trauma patients, with overall reported survival rates of 0% to 10%.[7–10] The absence of any widely used or accepted guidelines for pediatric ERT, as well as the low volume of experience at most centers, has led to significant variability in practices between surgeons and centers. This problem was highlighted when the American College of Surgeons Committee on Trauma published their guidelines for ERT, with the recommendation to use adult guidelines in children due to lack of robust evidence and experience in the pediatric population.[11] However, since that time a number of larger multicenter or national database studies of pediatric ERT have been published, and have identified areas of significant difference compared with the adult data.[12–16] In recognition of the need for an updated thorough review of the published literature and creation of evidence-based guidelines on pediatric ERT, a triorganization (EAST, WTA, and PTS) workgroup was established in October, 2020 to create two distinct but complementary work products; 1) a critical decisions algorithm and procedure guide designed for ease of use at the bedside and 2) a formal detailed systematic review and practice management guideline using Grading of Recommendations, Assessment, Development and Evaluation methodology. This article reports the results of the first of these two work products and was led by the WTA Algorithms Committee.

The algorithm (Fig. 1) and accompanying comments presented in this work represent a safe and sensible approach to the evaluation and initial management of the pediatric trauma patient with profound shock or traumatic arrest who may be a candidate for ERT. We recognize that there will be multiple factors that may warrant or require deviation from any single recommended algorithm, and that no algorithm can completely replace expert bedside clinical judgment. We encourage institutions to use this as a general framework in the approach to these patients, and to customize and adapt the algorithm to better suit the specifics of that program or location. We have also provided an accompanying basic procedural guide and sequence of steps for a standard pediatric ERT (Fig. 2). The guide presents an ordered and logical progression of maneuvers based on the patient status and operative findings during the procedure, but we recognize that the exact steps and sequential order may vary significantly based on both patient/injury factors and provider preference.

ALGORITHM AND PROCEDURE GUIDE

The following lettered sections correspond to the letters (blue circles with yellow font) identifying specific areas of the algorithm shown in Figure 1. In each section we have provided a brief summary of the important aspects and options that should be considered at that point in the evaluation and management process. The final lettered section provides a brief review of the ERT procedure guide shown in Figure 2.

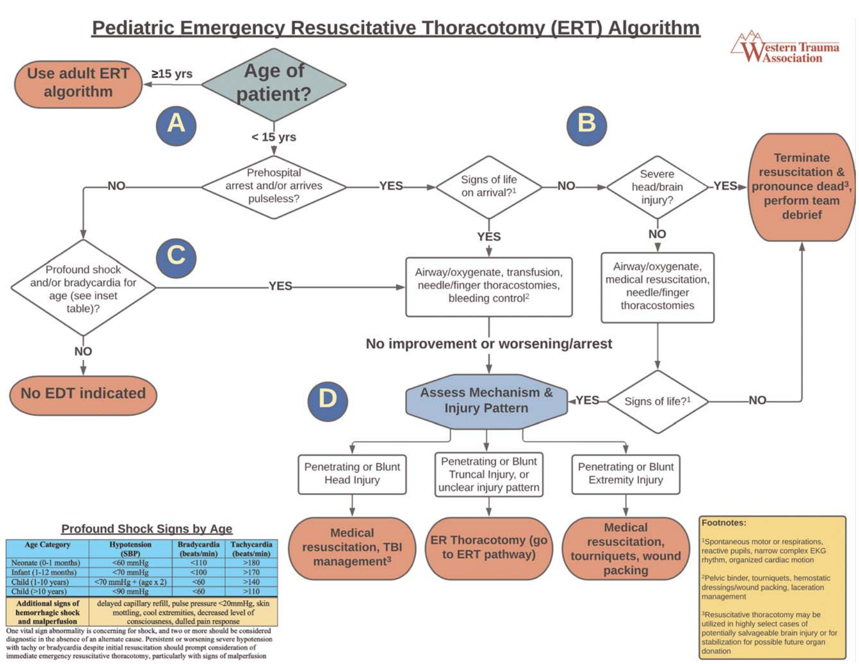

Figure 1. Clinical algorithm and footnotes for pediatric ERT. Circled letters correspond to sections in the associated article.

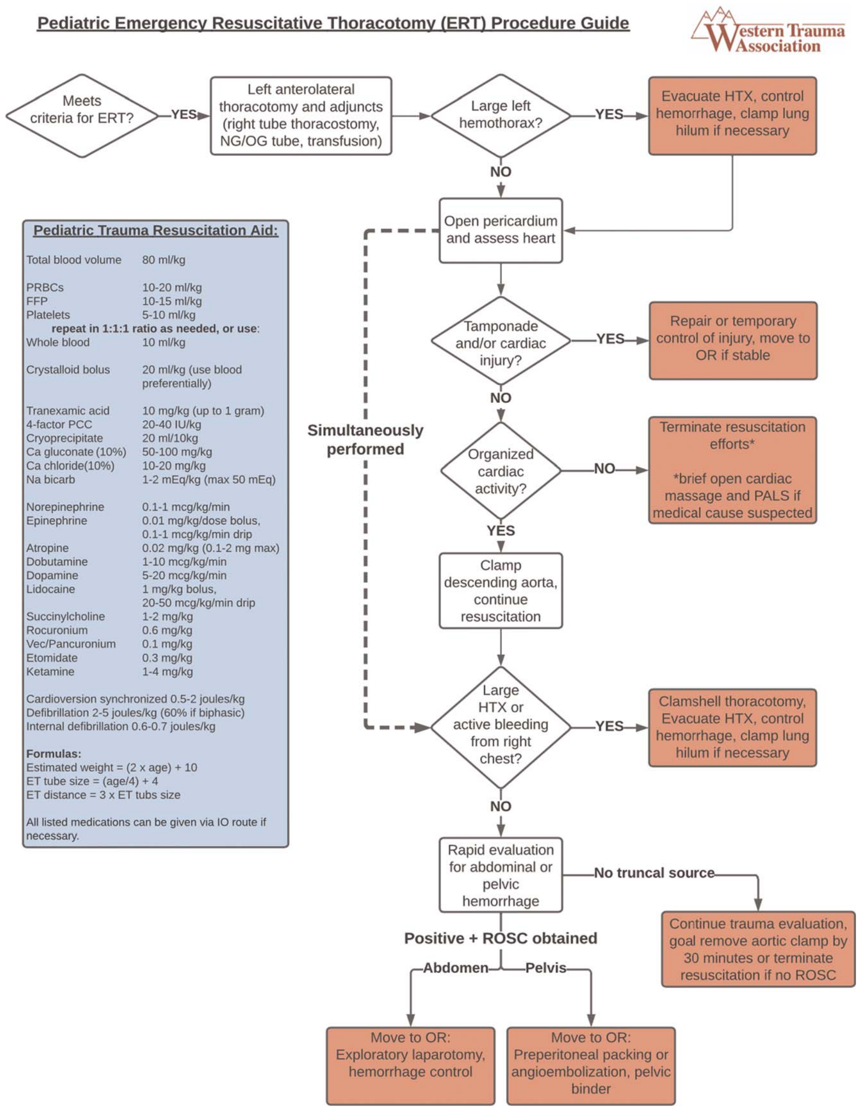

Figure 2. Pediatric ERT procedure guide and sequence (inset with reference guide for emergency drug and fluid/blood product dosing and formulas).

(A) Patient Selection and Arrival Status

For the purposes of this algorithm, "pediatric" is defined as younger than 15 years, with all older patients directed to the algorithm for ERT in adults.[5] The age criteria and cutoffs for pediatric versus adult classification varies widely in both the literature and in clinical trauma practice, with no universally accepted definitions. This is discussed further in the section below on areas of controversy and knowledge gaps. We elected to use an age cutoff of younger than 15 years to define the target population for this algorithm based on several of the larger and more recent studies that indicate an inflection point around this age that seems to differentiate outcomes between the two populations.[12,14,16–18] This is particularly relevant for pediatric patients with prehospital arrest who arrive pulseless, as several series reported a small number of survivors in this category but those patients were all in the adolescent (age >15) age range. For all pediatric patients, the initial decision mode is directed by whether there was a prehospital traumatic arrest and/or the patient arrives in pulseless arrest. Patients with traumatic arrest then proceed to section B, and patients who are not in arrest then undergo rapid primary survey, obtaining of initial vital signs, and cardiac rhythm monitoring. They then should be evaluated for the presence of profound shock and/or bradycardia as outlined in section C. If neither of these is present, then a standard trauma evaluation and workup is performed.

(B) Initial Evaluation of the Pulseless Patient

A rapid initial evaluation of the patient who arrives in extremis should be performed with the primary aims of identifying any immediately reversible causes of profound shock or arrest, initiating any potentially lifesaving interventions, and selecting the patient who may benefit from ERT. For the patient who arrives without palpable pulses, there should be an initial search for any evidence of salvageability using a group of findings commonly denoted as "signs of life."[19–21] Although a wide variety of findings have been characterized and used in the literature as a sign of life, there are no consensus guideline definitions currently available. For the purposes of this algorithm, we elected to use the same definition as the previously published EAST Practice Management Guideline for adult ERT.[4] This includes spontaneous movement or respirations, reactive pupils, narrow complex EKG rhythm, or organized cardiac motion on ultrasound examination. If signs of life are present then initial resuscitation focused on oxygenation/ventilation, volume expansion/transfusion, bleeding control, and bilateral needle or finger thoracostomies is performed if indicated. If no return of spontaneous circulation (ROSC) is immediately obtained, then the decision for or against ERT is based on the injury mechanism and pattern as outlined in section D. However, we emphasize that in these situations where seconds count, all of the above evaluation should be done simultaneously and there should be no delay to proceeding with an ERT if the managing surgeon deems it indicated. Unnecessary delays for prolonged evaluations, low-yield interventions, or to wait for the results of prolonged resuscitative efforts should be avoided to optimize the chance of salvage of the patient.

For patients with no signs of life and clear signs of severe brain injury as the primary cause of arrest we recommend early termination of resuscitation given the high associated mortality and likelihood of poor neurologic outcomes. We do note that ERT may be used in highly selected patients in this category with the rationale of attempting to preserve the option for family visitation prior to death and/or to facilitate potential organ donation, although this raises several ethical issues that are outlined below for areas of controversy.[22] For all others, initial resuscitation/interventions are performed as outlined above and the decision for proceeding to ERT versus termination of resuscitation are based on the return of ROSC or any signs of life as outlined in section D.

(C) Evaluation and Interventions for Severe Shock

Although ERT is primarily used in patients who present in traumatic arrest or who quickly progress to pulselessness after arrival, there is also a role in highly select patients with measurable vital signs and evidence of profound shock or impending cardiopulmonary arrest. Although the concepts in this area of the algorithm are identical to those in adult patients, the application in pediatric patients is much more complicated due to the large amount of age-related variation in both normal and abnormal vital signs and response to hemorrhage.[21,23,24] The inset table in the algorithm (Fig. 1) provides a breakdown of standardly used vital sign changes characteristic of hypotension, bradycardia, and tachycardia for neonates, infants, younger children, and the older child or adolescent. It is critical for the managing physician to appreciate the general principles that pediatric patients can maintain a relatively normal blood pressure even with ongoing large hemorrhage, that worsening tachycardia will be the usual primary sign of bleeding, and that a change from tachycardia to bradycardia is an ominous sign that usually immediately proceeds progression to full arrest.[24] Another potential option in this patient population or those who arrive without pulses is resuscitative endovascular balloon occlusion of the aorta (REBOA).[25] Given the lack of any significant modern case series or clinical data on REBOA use in the pediatric trauma patient it was not incorporated into this algorithm, and is further discussed below in the section on areas of controversy and knowledge gaps.

(D) Selection for Emergency Resuscitative Thoracotomy With Signs of Life

The primary factors that have been shown to impact the likelihood of survival and neurologically-intact survival in both adult and pediatric patients undergoing ERT include the presence or absence of vital signs or signs of life, the location of arrest (prehospital vs. in-hospital), and the injury patterns and mechanism.[4,10,14,26–28] This results is marked variability in prognosis between populations, ranging from 0% to 5% survival among blunt trauma patients with prehospital arrest to 80% or greater survival among thoracic stab wounds who arrive with vital signs present.[4,10,12,14] Among pediatric patients who arrive without signs of life and who do not regain any signs of life with the initial resuscitation efforts and interventions previously described, we recommend against performing an ERT. Termination of resuscitation efforts or a continued period of medical resuscitation should be performed based on the individual injury patterns and scenario. For those patients with at least one sign of life present or those in profound shock with impending arrest, the decision for ERT is then based on categorization of the mechanism and injury pattern into one of three groups. For patients with isolated penetrating or blunt head/brain injury we recommend continued medical resuscitation and traumatic brain injury (TBI) management and against routine ERT. However, highly selective ERT may be used in this patient population as outlined in section B although it remains an area of significant controversy. For patients with penetrating or blunt truncal injury, or an unclear injury pattern, we recommend proceeding with ERT barring any coexisting contraindication (such as associated severe TBI or clearly nonsurvivable injuries on external examination). Figure 2 shows our associated ERT procedure guide including a prioritized approach to the steps and sequence for performing a pediatric ERT that is described in more detail in section E below. Finally, for patients with arrest or profound shock secondary to penetrating or blunt extremity injury and no signs of truncal hemorrhage we recommend continued medical resuscitation in addition to ensuring extremity bleeding control with adjuncts including tourniquets, hemostatic dressing application, and direct pressure.

It is important to note that this area is where this algorithm and the available literature differentiates the outcomes between ERT in the adult versus pediatric populations. Unlike most other injuries where pediatric patients have significantly better outcomes compared with similarly injured adults, among patients with prehospital traumatic arrest the already poor outcomes for adults are even worse by comparison in children.[12,14,16] This is likely a reflection of the greater compensatory responses to major hemorrhage in children that allow for the maintenance of vital signs at greater degrees of hemorrhage compared with adults. There is also a shorter temporal window of tolerance to hypoxia and cardiac/cerebral ischemia among children, and thus children who progress to traumatic arrest with no signs of life are more likely to be at an irreversible point of exsanguination and/or ischemia. Table 1 shows a comparison of the recommendations for or against ERT in adults based on the 2015 EAST practice management guideline (PMG) versus for children based on this algorithm.[4] Whereas the adult guideline differentiates the recommendations for patients without signs of life based on mechanism, this algorithm recommends against ERT for children

TABLE 1. Comparison of Recommendations for Emergency Resuscitative Thoracotomy in Children From This Algorithm Versus Adults Based on the EAST Practice Management Guideline (Shaded Areas Highlight Key Differences)

	Recommendation	
ER Thoracotomy Indication	**EAST Adult PMG***	**Pediatric WTA Algorithm**
1. Penetrating thoracic trauma with signs of life but pulseless on arrival (Strong)	YES	YES
2. Penetrating thoracic trauma without signs of life and pulseless on arrival (Conditional)	YES (conditional)	NO
3. Penetrating extra-thoracic (noncranial) trauma with signs of life but pulseless on arrival (conditional)	YES (conditional)	YES
4. Penetrating extra-thoracic (noncranial) trauma without signs of life, pulseless on arrival (conditional)	YES (conditional)	NO
5. Blunt injury with signs of life but pulseless on arrival (Conditional)	YES (conditional)	YES (truncal only)
6. Blunt injury without signs of life and pulseless on arrival	NO	NO

*Recommendations extrapolated from the 2015 EAST PMG on adult emergency department thoracotomy.[4]

who present pulseless and without any other sign of life regardless of penetrating versus blunt mechanism. This issue and the relevant literature are discussed in further detail in the section below on areas of controversy and existing gaps. It is also important to recognize that this algorithm should be used as a general guideline and not an absolute dictum forbidding ERT in this population. In select patients with penetrating truncal injury and loss of reported signs of life immediately prior to arrival or with unclear presence of signs of life, it is perfectly reasonable to err on the more aggressive side and perform ERT based on the determination of the managing surgeon. Finally, this algorithm uses a cutoff age of 15 years to differentiate between pediatric versus adult based on ERT outcome differences noted in multiple series but the size and physical maturity of an individual adolescent patient should be taken into account.[10,12,14,16] The general effect of age on outcomes in these series demonstrates an inverse correlation between age and mortality, with patients on the younger end of the spectrum having significant higher mortality compared with older children and adolescents.

Although pediatric ERT can be a lifesaving procedure, the more likely outcome in this patient population is an unsuccessful resuscitation and termination of efforts. The experience of the death of a child can be particularly challenging even for medical professionals who routinely manage trauma patients, and we recommend a team debrief after these difficult events. Such intense and critical experiences can be associated with significant grief, guilt, increased stress responses, and emotional burnout or moral distress. Hospitals should provide resources such as mental health counseling, spiritual support, and opportunities to discuss such events. Debriefing following a death can assist health care providers by reviewing the team's performance and identifying possible areas of improvement.[29] Various publications have noted that immediate debriefing was associated with a higher degree of accuracy or recalling details of the resuscitation, improved well-being, and can potentially reduce medical errors.[30–32] Structured debriefing with formal training can also improve communications among providers and potentially mitigate the emotional trauma from the loss of a child.[33]

E. Pediatric ERT Procedure Guide and Sequence

Figure 2 contains a flowchart style procedural guide to performing an ERT in a pediatric trauma patient in extremis or in traumatic arrest. This represents a standardized logical and sequential approach to the procedural steps and order of priorities based on consensus opinion of the author group, but the exact sequence and steps may vary based on individual patient physiology, injuries, response to resuscitation/interventions, available resources, and surgeon preference. At the initiation of the ERT procedure there should be simultaneous placement of a right tube thoracostomy to evaluate for contralateral hemorrhage and the need for extension to a bilateral (clamshell) thoracotomy. Placement of a nasogastric or orogastric tube is important for assistance in delineating the esophagus from the descending aorta prior to cross-clamping and for decompression of the stomach which can be significantly distended in pediatric patients. The first priority should then be evacuation and control of any left chest hemorrhage with simultaneous conversion to a clamshell thoracotomy if there is evidence of significant right thoracic hemorrhage. The next sequence of steps involves opening the pericardium and assessing for cardiac injuries and tamponade, assessing for organized cardiac activity and performing open cardiac massage if indicated, and cross-clamping the descending aorta to augment central perfusion. If there is no organized cardiac activity with the resuscitative measures listed above and no identified immediately reversible cause, then resuscitation efforts should be terminated. If there is organized cardiac activity and no identified source of hemorrhage in the thoracic cavity, then rapid evaluation for abdominal and pelvic hemorrhage should be performed. This may include abdominal sonography, diagnostic peritoneal aspirate, pelvic examination and radiography, or a mini-laparotomy incision. The patient should then be moved rapidly to the operating room for definitive abdominopelvic hemorrhage control via exploratory laparotomy and/or preperitoneal pelvic packing along with exploration and closure of the thoracotomy incision. In highly select cases where the hemorrhage source is localized to the pelvis and the patient has stabilized with ERT and resuscitation, then angioembolization either in an interventional radiology suite or hybrid operating room may be performed. Figure 2 also includes an inset guide to common pediatric emergency drug dosing, resuscitation product volumes, and formulas for estimating patient weight and the ideal endotracheal tube size.

AREAS OF CONTROVERSY AND EXISTING KNOWLEDGE/RESEARCH GAPS

Although the group of authors representing three major trauma societies and both adult and pediatric surgical specialties was able to achieve consensus on this pediatric ERT algorithm and procedure guide, there are numerous specific aspects that remain areas of controversy and that warrant further discussion. A full discussion of every controversy or knowledge gap around this topic is beyond the scope of this article, and this section will focus on the areas that generated the most discussion and debate throughout the algorithm development and open commentary period. In addition, several of these areas are featured in the audio recording (Supplemental Digital Content 2, http://links.lww.com/TA/D91) of the algorithm presentation and question/answer period from the 2022 WTA meeting.

The first area of controversy that is common to all aspects of pediatric trauma is how to best define the "pediatric" population in terms of age groups or cutoffs. This is a highly complex and multi-faceted problem that can never be fully addressed by simply picking an age cutoff that creates a simple binary of "pediatric" versus "adult". Ideally, the selected criteria would reliably separate the population into clinically relevant and distinct cohorts with different outcomes to the same intervention. Although the most commonly used cutpoint to define pediatric patients in the trauma literature is age less than 18 years (with some even using age younger than 21 years), this is based on a legal definition and not a physiologic or epidemiologic rationale.[3,17,18,23] In their analysis of ERT outcomes over a 40-year period, Moore and colleagues[14] demonstrated a significant difference in survival rates around the age cutoff of 15 years, with a 5% survival in adolescents (15–18 years) versus 0% in their pediatric cohort (<15 years). Similar results have been reported in several more recent nationwide analyses of pediatric ERT, including significantly lower survival rates for children compared with both adolescents and adults.[13,16,34] This includes consistent reports of no survivors of pediatric ERT with blunt traumatic arrest, or with penetrating trauma and no signs of life on arrival.[10,13,16,21,23,27,34] This effect does not appear to be limited to the small cohort undergoing ERT as demonstrated in a nationwide analysis of all deaths after trauma that found a higher incidence of early mortality among children versus similarly injured adults.[24] Similar findings were identified by Prieto and colleagues[16] who analyzed the National Trauma Data Bank and found that there were no survivors among pediatric patients who arrived without signs of life for both blunt and penetrating trauma mechanisms. These data contradict the commonly held notion that injury tolerance and survival are always better in pediatric patients compared to adults, and in the case of this algorithm it supports a more restrictive approach to ERT in pediatric patients compared to standard criteria used in adults.[4,5] There was debate about how to handle emergency situations where the age of the patient is unknown, with options of using proxies including height/weight, Tanner stage, or Broselow tape color category. Although no methodology was felt to be superior or highly reliable, the consensus was that size and Tanner stage should be used as proxies in these situations until an accurate age is obtained.

The other main area of controversy, and divergence from the adult guidelines on ERT, was the criteria for withholding ERT and/or terminating resuscitation in the pediatric patient with out-of-hospital traumatic arrest. Termination of resuscitation (TOR) in trauma can be a challenging decision especially when it involves the care of a child. Although there are a few consensus articles on pediatric patients who experience a cardiac arrest in trauma, there is still significant controversy about the role of ERT in this patient population.[20,35] A joint position statement focused on TOR after out-of-hospital cardiac arrest was published in 2014 that involved the American College of Surgeons, the American College of Emergency Physicians, the American Academic of Pediatrics, and the National Associations of EMS Physicians.[28] This evidence-based review determined that if a pediatric trauma patient has experienced a cardiac arrest and the resuscitation is beyond 30 minutes or the nearest facility is more than 30 minutes away, TOR should be considered after discussions with the family and medical personnel. This is based on the high likelihood of death and poor prognosis in this scenario.[36–38] Although this work proposed 30 minutes from arrest as a relevant cutoff, several recent series have established that a more relevant metric may simply be the presence of signs of life on arrival to the trauma center.[10,14,16,34,35] These series have examined outcomes in cohorts undergoing ERT and in the larger cohort of all pediatric trauma patients with posttraumatic cardiac arrest. They have consistently demonstrated a dismal prognosis for overall survival and for survival with intact neurologic function among pediatric patients with out-of-hospital arrest and no signs of life on presentation. Unlike the adult population where ERT criteria are more liberal after penetrating trauma, this also does not appear to differ between blunt and penetrating mechanisms.[16,34,39] The most recent national-level analysis of pediatric ERT from the National Trauma Data Bank (NTDB) found no survivors in the cohort with prehospital arrest and no vital signs on arrival, with no difference between the blunt versus penetrating injury subgroups.[16] Although overall survival following ERT in children is higher with penetrating mechanisms compared with blunt trauma, this appears to be primarily due to a higher incidence of ROSC with initial field resuscitation and interventions.[12,27] Among the patients who arrive with no signs of life, survival and neurologic recovery appear to be similarly negligible between blunt and penetrating cohorts.[9,12,16,27] In addition, the rates of ROSC and survival to hospital discharge have been reported to be equivalent or better with medical resuscitation and closed cardiac compressions compared with ERT and open cardiac massage.[13,20,21,27,34,35,38] The low survival rate in children without signs of life at presentation may be due to their unique physiology and reserve compared with adults. Children will obviously be starting with a lower total blood volume than adults, and with the smallest children having the least amount of circulating blood and thus subject to exsanguination with less total blood loss versus adolescents or adults. It is also well known that pediatric trauma patients are better able to compensate for blood loss with greater vasoconstriction and maintenance of normal range blood pressures, and thus acute hemodynamic decompensation happens later and represents a greater degree of hemorrhagic shock and blood loss versus similarly injured adults.[40] Furthermore, unlike elderly patients, cardiac arrest in children is not typically sudden and indicates a complete decline of respiratory and circulatory function, usually as a result of acute blood loss.[19,41,42]

There are also concerns about the potential adverse impacts and risks associated with ERT, particularly in cases with a low probability of survival. This was highlighted in a 2012 review of the "societal costs" by Passos and colleagues.[43] Among 123 ERTs, 51% were considered to be performed for inappropriate indications with no survivors or resultant organ donors salvaged.

In addition, these cases expended considerable resources including 335 units of blood and 6 operating room visits, and resulted in three needlestick injuries to bedside providers. A subsequent prospective multicenter series identified a 7.2% incidence of occupational exposures during ERT, with the number of exposures exceeding the number of ERT survivors.[44] These potential adverse effects on resource consumption and injuries to trauma team personnel must be considered and should be of more concern in the current era where there are nationwide shortages of hospital personnel and blood product supplies related to the COVID pandemic.[45–47] Another area of debate and discussion was the utility and ethics of performing ERT on patients with clear signs of nonsurvivable TBI to potentially facilitate salvage for later organ donation, although there is scant available evidence on this topic. While Passos and colleagues[43] reported no organ donors salvaged in their series of 125 ERTs, Schnuriger and colleagues[23] analyzed 263 ERTs and identified three patients (1.1%) who were salvaged and went on to donate a total of 11 organs. Although there is a clear societal benefit to facilitating additional organ donation, this practice raises significant ethical concerns around conflict of interests as the primary responsibility of the managing trauma team is to the patient and not to theoretical future organ recipients.[48,49] A counterargument to this position is that performing an ERT is these cases can facilitate family presence for these difficult decisions and at the time of death, and can support the patient's and families wishes for organ donation. However, this would entail a priori knowledge of the patient and/or family's wishes around organ donation. Given the highly invasive nature of ERT, the high resource utilization, exposure risks to the surgical team, and the ethical issues noted above, the group consensus was that ERT to solely facilitate potential organ donation should not be routinely performed but may be pursued in select situations.

One approach that has been proposed as a safer and less invasive alternative to ERT is REBOA.[50] Although there is a relatively robust and growing body of literature in the adult trauma population, the published experience with REBOA in the pediatric population is primarily limited to animal models, radiologic mapping/measuring for theoretical deployment, and case reports.[50–54] Several larger case series using national databases or registries have been published, but the analysis of pediatric REBOA use and outcomes have been almost exclusively in the adolescent/young adult age range of 16 to 18 years.[50,54,55] Given the lack of data and experience with REBOA in the true pediatric age range the group consensus was to not include it as a recommended option or pathway in this algorithm. However, it was noted that the recent development and approval of smaller profile REBOA catheters (4 Fr) may enable extension of this as a therapeutic option for select pediatric patients in extremis or traumatic arrest in the near future.[56]

It is also important to note that there are many areas of this algorithm that lack high quality evidentiary support, and where further focused research is required. Table 2 provides a list of the most important specific topics or existing research "gaps" related to this topic that were identified by the authors during the development of this algorithm. In addition, it is important to understand that much of the existing evidence is limited to small, single-center series that have detailed clinical data but that lack adequate power for valid advanced statistical analyses, or large database analyses with much larger sample sizes but that lack clinical granularity. Thus, many aspects of this algorithm are based on lower-quality evidence and/or expert opinion and should be thought of as a framework for management but not an absolute dictum for the treatment of any individual patient.

SUMMARY AND CONCLUSION

The management of pediatric trauma patients with postinjury cardiopulmonary arrest or impending arrest requires rapid and sound clinical decision making that frequently includes consideration for performing an emergency resuscitative thoracotomy. This work provides an up-to-date and evidence-based approach to this process and to the selection of patients who may benefit from ERT, and those where the available evidence suggests little to no benefit. The primary selection for ERT in the pulseless pediatric patient should be based on the presence of any signs of life on hospital arrival and during the initial evaluation, and the anatomic injury pattern and not on injury mechanism alone or as a deciding factor.

TABLE 2. Top Identified Knowledge and Research Gaps Related to Pediatric ERT

Topic or Research Gap	Algorithm Section
1. Optimal definition and consensus agreement for age cutoffs and definitions of pediatric versus adult	A
2. Clinically relevant criteria for grouping of pediatric patients into age cohorts that would impact management decisions and optimal interventions	A
3. Consensus definitions of individual factors that represent "signs of life", and comparison of predictive and prognostic implications between individual signs of life	B
4. Role of ERT in pediatric patients with presumed severe brain injury and incidence of conversions to organ donation	B
5. Role of resuscitative endovascular balloon occlusion (REBOA) in pediatric trauma patients with hemodynamic instability or impending arrest	B and C
6. Optimal criteria for identifying profound shock or impending cardiopulmonary arrest, and performing ERT prior to arrest	C
7. Delineation of optimal age categorization with associated hemodynamic manifestations of profound shock and predictors of impending cardiopulmonary arrest	C
8. Identification of any subgroups of penetrating or blunt head injury with signs of life that may benefit from ERT versus medical resuscitation	D
9. Identification of any subgroups of penetrating or blunt extremity injury with signs of life that may benefit from ERT versus medical resuscitation	D
10. Comparison of medical resuscitation and closed chest compressions versus ERT and open cardiac massage among pediatric trauma patients and relevant age and injury-specific subgroups	D

AUTHORSHIP

All authors meet authorship criteria for this article as described below. All authors have seen and approved the final article as submitted. The first author (M.M.) had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. M.J.M., R.I., M.J. participated in the conception and design. M.J.M., M.C., K.M., R.I., S.L., K.T.F.O.-B., G.N., L.S., M.J. participated in the acquisition of data. K.T.F.O.-B., C.V.R.B., J.L.H., M.dM., K.I., E.J.L., E.E.M., K.A.P., A.G.R., N.G.R., J.A.W., R.C. participated in the analysis and interpretation of data. M.J.M., L.S., M.J., R.I. participated in the drafting of the article. K.T.F.O.-B., C.V.R.B., J.L.H., M.dM., K.I., E.J.L., E.E.M., K.A.P., A.G.R., N.G.R., J.A.W., R.C., M.C., K.M., R.I., S.L., K.T.F.O.-B., G.N., M.J. participated in the critical revision of the article. M.J.M., K.M., L.S., M.J. were the statistical expertise. R.C., M.J., K.M. participated as the administrative, technical, or material support. M.J.M., KI, R.C., R.I., L.S., M.J. participated in the supervision.

DISCLOSURE

The authors declare no funding or conflicts of interest.
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