EMA Emergency Medicine Australasia

Emergency Medicine Australasia (2023) **35**, 412–419 doi: 10.1111/1742-6723.14141

ORIGINAL RESEARCH

Mid-Arm Point in PAEDiatrics (MAPPAED): An effective procedural aid for safe pleural decompression in trauma

Nuala QUINN ,[1,2,3] Grantley WARD,[4] Cyril ONG,[5] David KRIESER ,[2,4,6] Robert MELVIN ,[7] Allya MAKHIJANI,[6] Joanne GRINDLAY,[2,8,9] Catherine LYNCH,[1] Gabrielle COLLERAN,[10,11] Victoria PERRY,[12] Sinead M O'DONNELL,[2,8] Ian LAW,[6] Dinesh VARMA,[13,14] John FITZGERALD,[15] Hannah J MITCHELL[16] and Warwick J TEAGUE [9,12,17,18,19]

[1]Department of Paediatric Emergency Medicine, Children's Health Ireland at Temple Street, Dublin, Ireland, [2]Emergency Research Group, Murdoch Children's Research Institute, Melbourne, Victoria, Australia, [3]National Office for Trauma Services, Dublin, Ireland, [4]Melbourne Medical School, The University of Melbourne, Melbourne, Victoria, Australia, [5]Department of Medical Imaging, The Royal Children's Hospital, Melbourne, Victoria, Australia, [6]Department of Emergency Medicine, Sunshine Hospital, Western Health, Melbourne, Victoria, Australia, [7]Department of Emergency Medicine, Sandringham Hospital, Alfred Health, Melbourne, Victoria, Australia, [8]Department of Emergency Medicine, The Royal Children's Hospital, Melbourne, Victoria, Australia, [9]Department of Paediatrics, The University of Melbourne, Melbourne, Victoria, Australia, [10]Department of Paediatric Radiology, Children's Health Ireland at Temple Street, Dublin, Ireland, [11]Department of Paediatrics, Trinity College Dublin and the National Maternity Hospital, Dublin, Ireland, [12]Trauma Service, The Royal Children's Hospital, Melbourne, Victoria, Australia, [13]Department of Radiology, The Alfred Health, Melbourne, Victoria, Australia, [14]Department of Surgery, Monash University, Melbourne, Victoria, Australia, [15]Western Health Medical Imaging, Sunshine Hospital, Western Health, Melbourne, Victoria, Australia, [16]Mathematical Sciences Research Centre, Queen's University, Belfast, UK, [17]Department of Paediatric Surgery, The Royal Children's Hospital, Melbourne, Victoria, Australia, [18]Surgical Research Group, Murdoch Children's Research Institute, Melbourne, Victoria, Australia, and [19]School of Public Health and Preventive Medicine, Monash University, Melbourne, Victoria, Australia

Abstract

Objective: Life-threatening thoracic trauma requires emergency pleural decompression and thoracostomy and chest drain insertion are core trauma procedures. Reliably determining a safe site for pleural decompression in children can be challenging. We assessed whether the Mid-Arm Point (MAP) technique, a procedural aid proposed for use with injured adults, would also identify a safe site for pleural decompression in children.

Methods: Children (0–18 years) attending four EDs were prospectively recruited. The MAP technique was performed, and chest wall skin marked bilaterally at the level of the MAP; no pleural decompression was performed. Radio-opaque markers were placed over the MAP-determined skin marks and corresponding intercostal space (ICS) reported using chest X-ray.

Results: A total of 392 children participated, and 712 markers sited using the MAP technique were analysed. Eighty-three percentage of markers were sited within the 'safe zone' for pleural decompression (4th to 6th ICSs). When sited outside the 'safe zone', MAP-

Key findings

- In children as in adults, the MAP is a reliable guide to site the incision for emergency pleural decompression in the 'safe zone' (4th to 6th ICSs).
- MAP technique will site pleural decompression in the 'safe zone' in 9 out of 10 children when used with an age-based adjustment to account for differences in arm *versus* chest growth rates, the MAPPAED rule.
- MAPPAED rule: in children aged ≥4 years, use the MAP technique and go UP one ICS to reliably hit the 'safe zone', whereas in children <4 years use the MAP technique without adjustment.

Correspondence: Associate Professor Warwick J Teague, Trauma Service, The Royal Children's Hospital, 50 Flemington Road, Parkville, VIC 3052, Australia. Email: warwick.teague@rch.org.au

Nuala Quinn, MBChB, FRCPI, Paediatric Emergency Medicine Physician; Grantley Ward, B-BMed, MD, Resident Medical Officer; Cyril Ong, FRCR, FRANZCR, Paediatric Radiologist; David Krieser, MBBS, FRACP, Paediatric Emergency Medicine Physician; Robert Melvin, MBBS, FACEM, Emergency Medicine Physician; Allya Makhijani, MBBS, MM (Paed), Paediatrician; Joanne Grindlay, MBBS, FACEM, Paediatric Emergency Medicine Physician; Catherine Lynch, MB, FRACP, Paediatrician; Gabrielle Colleran, MD, MB BCh, BAO, Paediatric Radiologist; Victoria Perry, BMedSci, MBBS, FRACP, Paediatrician; Sinead M O'Donnell, MB, MD, Paediatric Emergency Medicine Physician; Ian Law, Registered Nurse; Dinesh Varma, MBBS, FRANZCR, Radiologist; John Fitzgerald, BSc, BMedSci, MBBS, FRANZCR, Radiologist; Hannah J Mitchell, PhD, Statistician; Warwick J Teague, DPhil, FRACS, FRCSEd, Director of Trauma Services, Paediatric and Burns Surgeon.

Accepted 21 October 2022

determined markers were typically too caudal. However, if the site for pleural decompression was transposed one ICS cranially in children ≥4 years, the MAP technique performance improved significantly with 91% within the 'safe zone'.

Conclusions: The MAP technique reliably determines a safe site for pleural decompression in children, albeit with an age-based adjustment, the Mid-Arm Point in PAEDiatrics (MAPPAED) rule: 'in children aged ≥4 years, use the MAP and go up one ICS to hit the safe zone. In children <4 years, use the MAP.' When together with this rule, the MAP technique will identify a site within the 'safe zone' in 9 out of 10 children.

Key words: *chest drain, paediatric, pleural decompression, thoracic injuries, thoracostomy.*

Introduction

Traumatic injury is the leading cause of death in children worldwide and a leading cause of paediatric hospitalisation and long-term disability in many countries.[1–4] Traumatic brain injury is the leading cause of paediatric trauma death in most series. However, thoracic trauma is another leading contributor to this burden. A recent review of paediatric trauma in England and Wales reported the majority of trauma deaths occur in children with severe isolated brain injury, isolated chest injury or a combination of brain and chest injury.[5] Furthermore, a 10-year review of presentations to an Australasian paediatric major trauma centre showed children with severe thoracic trauma were 10 times more likely to die from their injuries.[6] Thus, emergency management of life-threatening thoracic trauma is of the utmost importance in the paediatric trauma resuscitation room.

Tension pneumothorax, massive haemothorax and cardiac arrest are traumatic life-threats managed during the primary survey, and require emergency pleural decompression. Traditionally decompression was achieved by needle thoracocentesis via the second intercostal space (ICS). However, it is now appreciated that emergency needle decompression can be unreliable and ineffective, with failure rates as high as 60%.[7,8] Therefore, thoracostomy has been adopted by many mature trauma systems as the preferred method of emergency pleural decompression, both adult and paediatric.[6,9–13] As such, thoracostomy, followed typically by intercostal chest drain (ICD) insertion, are core procedures in trauma resuscitation.

Difficulties in identifying a safe site for thoracostomy and ICD insertion are well-recognised. Although a 'triangle of safety' for decompression can be defined anatomically (Fig. 1), these muscular boundaries are difficult to recall, especially under the pressures of trauma resuscitation. Studies report widespread difficulties recalling or applying these anatomical boundaries, with more than 40% of simulated or actual ICD insertions being outside the 'triangle of safety'.[14,15] A less memory-demanding definition of the 'safe zone' is that spanning the 4th to 6th ICSs, just anterior to the mid-axillary line.[11,16] Although easier to recall during trauma resuscitation, correctly counting ICSs can still be difficult in children and confound safe pleural decompression and thus an alternative is needed.

Marking the chest at a level corresponding to the Mid-Arm Point (MAP), halfway between the patient's acromion and olecranon process, has been reported to be a reliable aid to safely site pleural decompression in injured adults.[17] We hypothesised that the MAP technique would also accurately site emergency pleural decompression with the 'safe zone' for paediatric trauma patients. If so, the MAP technique would assist clinicians to deliver safe and effective paediatric trauma care under the cognitive and time pressures of trauma resuscitation.

Methods

Patient recruitment, inclusion and exclusion

Children (0–18 years) attending any one of four participating EDs were recruited into this prospective study by trained study team members. Any child who was attending the ED and having a chest X-ray (CXR) as part of their management was eligible for inclusion. No child had a CXR performed solely for the purpose of this study – they all had a CXR booked as predetermined part of their medical/surgical management. Parents/carers were given an information leaflet and signed consent was obtained. Patients were subsequently excluded if the CXR demonstrated non-compliant patient arm positioning (e.g. sterno-humeral angle less than 90°), or if the humerii could not be visualised. Additional exclusion criteria were: need to abandon marker placement or CXR because of child upset or non-

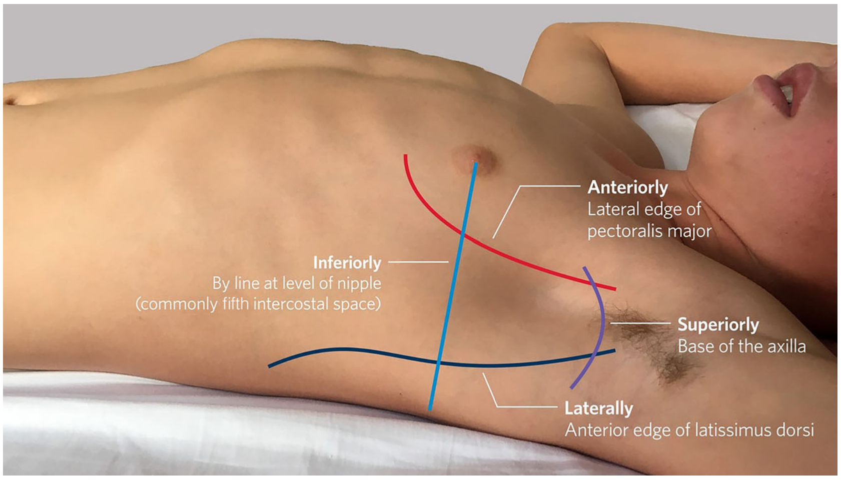

Figure 1. *Anatomical landmarks of the 'triangle of safety'.*

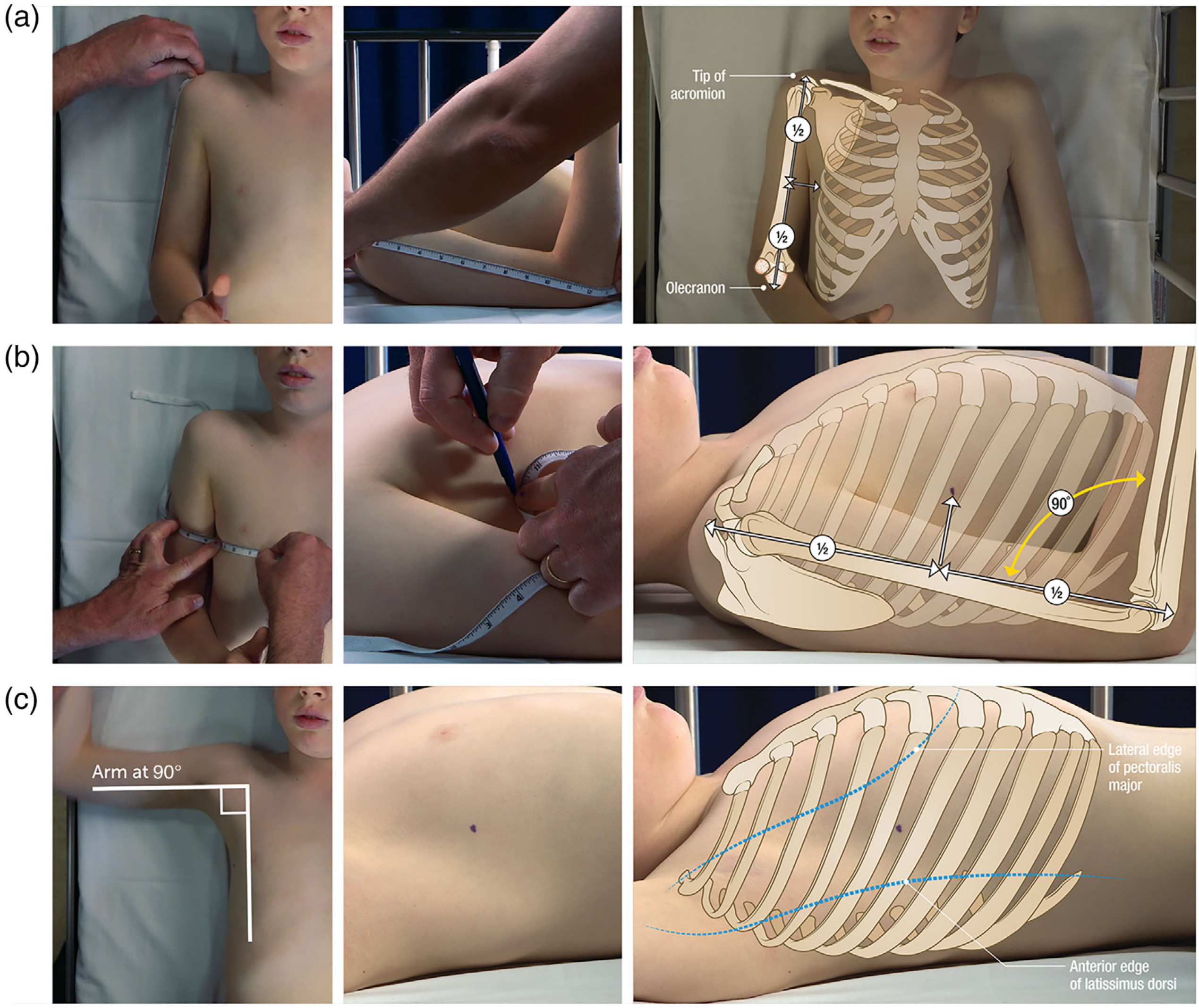

Figure 2. *Steps of the MAP technique. (a) With the child's arm adducted, a tape measure was used to determine the MAP. (b) A skin mark was placed on the adjacent chest wall at a level corresponding to the MAP. (c) The child's arm was then abducted to position the child's arm for pleural decompression, with the skin mark showing the site for either thoracostomy of chest drain insertion, with the added age-based adjustment of the MAPPAED rule in those children aged ≥4 years. These key steps mirror the MAP technique proposed for adult patients by Bing et al.*[17]

cooperation, and skeletal abnormalities which might confound chest wall anthropometry (e.g. osteogenesis imperfecta, scoliosis or kyphosis).

Study setting

Patients were recruited from the EDs of four hospitals. Two sites are major trauma services in stand-alone, tertiary paediatric hospitals (The Royal Children's Hospital [RCH], Melbourne, Victoria, Australia; Children's Health Ireland (CHI) at Temple Street, Dublin, Ireland). The other two sites are metropolitan trauma centres, which receive both adult and paediatric non-major trauma (Sandringham Hospital, Melbourne, Victoria, Australia; and Sunshine Hospital, Melbourne, Victoria, Australia).

MAP technique to determine site (ICS) for pleural decompression

To demonstrate the utility of the MAP technique in children, the MAP was measured and chest wall marked at the level corresponding to the MAP, at the anterior axillary line (Fig. 2).

Finally, in a step specific to the research method but divorced from clinical application of the MAP technique, a sticker with a 2.5 mm metal ball at its centre (BB marker) was placed over MAP-determined mark on the child's chest wall skin. The specific purpose of the BB marker was to allow accurate and reproducible reporting of the ICS corresponding to this skin mark on CXR. Whenever possible, the MAP technique was performed bilaterally prior to a single CXR.

Clinicians (consultants, fellows and an advanced nurse practitioner)

TABLE 1. *Performance of the MAP technique without age-specific adjustment (MAPPAED rule is not applied)*

Intercostal space	Age <4 years (n = 308)	Age ≥4 years (n = 404)	All ages (n = 712)
1–3 (too cranial)	21/308 (6.8%)	3/404 (0.7%)	24/712 (3.4%)
4–6 (safe zone)	281/308 (91.2%)	310/404 (76.7%)	591/712 (83.0%)
7–8 (too caudal)	6/308 (2.0%)	91/404 (22.6%)	97/712 (13.6%)

performing the MAP technique in children were first trained in process as above, including watching a 2-min educational video outlining key steps (Video S1). This study-specific video was produced by Creative Studio, RCH Melbourne, and accessible at all four sites using a Quick Response code displayed on study materials, or via a download link: https://player.vimeo.com/external/303203291.hd.mp4?s=5498a1be8bfccde4292ecc4b6c9ba4c11e1d25b2&profile_id=175.

Determination of the ICS corresponding to the MAP on chest X-ray

Children with BB markers attached underwent CXR as per their predetermined medical plan. To replicate the arm positioning for both thoracostomy and ICD insertion, CXRs were performed with the child's upper limbs abducted to at least 90° (Fig. 3). After the X-ray was performed, the position of the marker was checked to ensure that it was still in the position it was placed in.

The study team included a consultant radiologist at each participating site, who was responsible for the primary reporting of each CXR for their respective site. The radiologist was blinded from the skin marking process. A standardised reported approach was followed, namely: type of CXR (supine or erect), ICS position of the BB marker on the left and/or right side and sternohumeral angle. If a marker was found to overlie the rib rather than ICS per se, the radiologist assigned the marker to the space above the rib, in accordance with the clinical dogma to avoid neurovascular bundle injury during pleural decompression by going above the rib.

To assess interrater reliability in radiologist reporting, each site randomly selected and anonymised 10 CXRs for blinded and independent 'double-reading' by the other three radiologists. Secondary reports of double-reading were assessed for agreement or otherwise.

Statistical analysis

Statistical analyses were performed using The R Project for Statistical Computing (R version 4.1.0), and included Fisher's tests, odds ratio calculation with 95% confidence interval (CI) and McNemar tests for dependent samples; $P > 0.05$ considered significant.

Ethical considerations

Human Research Ethics Committee approval was gained at each participating site prior to commencement of recruitment at that site.

Figure 3. *Representative study chest X-ray showing BB markers and compliant patient positioning. The radio-opaque BB markers are evident on both left and right sides. Abduction of the arms and sterno-humeral angle are compliant with the study methods, and mirror the positioning used for patients undergoing pleural decompression.*

Results

Sample

The recruited cohort comprised 392 children. Of these, 24 children were excluded according to the criteria defined above: sterno-

TABLE 2. *Performance of the MAP technique with age-specific adjustment (MAPPAED rule is applied)*

Intercostal space	Age <4 years (n = 308)	Age ≥4 years (n = 404)	All ages (n = 712)
1–3 (too cranial)	21/308 (6.8%)	30/404 (7.4%)	51/712 (7.2%)
4–6 (safe zone)	281/308 (91.2%)	365/404 (90.4%)	646/712 (90.7%)
7–8 (too caudal)	6/308 (2.0%)	9/404 (2.2%)	15/712 (2.1%)

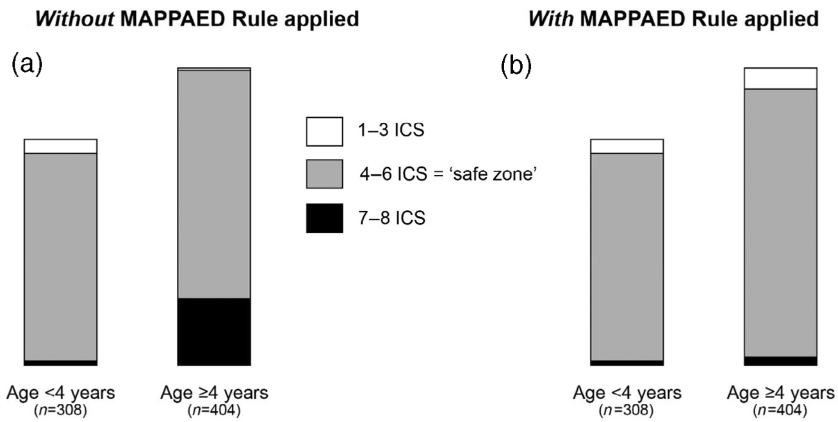

Figure 4. *The number and relative distribution of markers above (1–3 ICS), within (4–6 ICS) or below (7–8 ICS) the 'safe zone' for pleural decompression. Data are presented without (a) and with (b) the MAPPAED rule applied. The 'MAPPAED rule' is an age-specific adjustment in which the site for pleural decompression in children ≥4 years is one ICS more cranial than that corresponding to the MAP. No such age-specific adjustment is made for children <4 years.*

humeral angle less than 90°, $n = 14$; humerii not visualised, $n = 5$; need to abandon marker placement or CXR because of child upset or non-cooperation, $n = 5$. The 368 included children were aged between 4 months and 18 years. Three hundred and forty-four children had bilateral markers evident on CXR for reporting. The remaining 24 children had a single reportable marker, principally because of marker loss rather than unilateral application. Thus, 712 markers sited using the MAP technique as a guide were available for reporting on CXR and analysis. Laterality was evenly split, with 353 (50%) markers on the left side of the chest, and 359 (50%) on the right.

Performance of the MAP technique in children

Radiologist reporting demonstrated 591 (83%) markers sited using the MAP technique within the *a priori*-defined 'safe zone' for thoracostomy and chest drain insertion, that is, 4th to 6th ICSs (Table 1; Fig. 3). In all-ages, it was uncommon for the MAP to guide placement of a marker more cranial than the 'safe zone', with only 3% of markers sited cranial to the 4th ICS. More frequently however, the MAP technique sited the marker more caudal than the safe zone, with 97 markers (14%) sited in the 7th or 8th ICS.

The radiologist-reported data revealed a noteworthy interaction between patient age and the marker ICS position (Table 1; Fig. 4a). First, significantly more markers were located within the 'safe zone' for children aged <4 years compared with those aged ≥4 years; <4 years: 281/308 *versus* ≥4 years: 310/404, $P < 0.001$. Second, 91 (94%) of those 97 markers placed caudal to the 'safe zone' were on children aged ≥4 years. These observations prompted additional post hoc analyses dichotomised at different age thresholds, as outlined below.

Application of the MAPPAED rule for age-specific adjustment

Having observed a trend towards a too caudal position in children aged ≥4 years, we performed post hoc analyses to determine the impact on performance of the MAP technique, if a secondary adjustment was made such that the level determined for pleural decompression was one ICS more cranial than that identified by the MAP technique alone.

First, we investigated whether adjustment by one ICS more cranial should be applied to children of all ages, or only children over a specific age threshold. When making this cranial adjustment to children of all ages, there was no significant improvement in the overall proportion of number of markers placed within the 'safe zone' (original ICS 4–6 = 591/712 *vs* adjusted ICS 4–6 = 594/712; $P = 0.88$). The first age threshold at which this cranial adjustment made a significant difference in identifying the 'safe zone' (as compared to no adjustment) was when it was applied for children ≥3 years. However, the performance was found to be enhanced further when applied to children ≥4 years, with a significant difference in obtaining the 'safe zone' when making the adjustment by applying the Mid-Arm Point in PAEDiatrics (MAPPAED) rule for children ≥4 years compared to ≥3 years ($P < 0.001$). The same enhancement was not seen for yet further incremental increases in age threshold, with no significant difference when comparing adjustments for children aged ≥4 years and children aged ≥5 years or older.

Based on these analyses, we considered optimal performance of the MAP technique to identify the 'safe zone' was achieved when in conjunction with an age-specific adjustment, such that the site for pleural decompression is one ICS more cranial than that corresponding to the MAP for children ≥4 years. We have coined this adjustment here the Mid-Arm Point in PAEDiatrics or 'MAPPAED' rule.

Additional application of the MAPPAED rule improved the overall accuracy of the MAP technique from 83% to 91% (Tables 1,2; Fig. 4b). This enhanced performance was achieved by improving the accuracy of the technique in children ≥4 years from 77% to 90% (Tables 1,2; Fig. 4b). Indeed, application of the MAPPAED rule increased the odds of the MAP technique identifying a site for pleural decompression in a child's 'safe zone' threefold in all ages (with MAPPAED rule: 646/712 vs without MAPPAED rule: 591/712, odds ratio [OR] 3.04 with 95% confidence interval [CI] 1.04–4.88).

Finally, McNemar tests for dependent samples were used to further analyse for significant differences in the performance of the MAP technique to identify a site within the 'safe zone' with *versus* without age-specific adjustment with the MAPPAED rule. McNemar test results were highly significant, with $P < 0.001$, for both an analysis of all ages as well as sub-group analysis for only children ≥4 years, affirming a benefit of using the MAPPAED rule in children ≥4 years.

Interrater reliability of chest X-ray reporting

Each site was given 10, randomly selected CXRs from the three other sites. After excluding markers that were not clearly visible (because of the picture taken in the radiology department and not the study itself) there were 231 markers that were double read. 230/231 (99.6%) were either in the same ICS or had maximum one ICS difference. In addition, although the reported level of some of markers differed by one ICS on double-reading, the subsequent determination of a marker to be within or outside the 'safe zone' for pleural decompression was unchanged for 191/231 (84.4%) of double-read markers.

Discussion

This study addresses a key deficit: the ability to rapidly, reliably determine a safe site for pleural decompression in severely injured children. Incorrect siting of ICD insertions in trauma is common, with an audit of 1000 ICD insertions performed at a major trauma service in South Africa showing that even in this expert and high-volume institution, 41% were inserted outside the 'triangle of safety'.[15] Another audit of ICD insertions in the ED setting reported complications in 37%, the majority of which were related to incorrectly sited and/or positioned ICDs.[18]

In adults, the MAP technique has been proposed as a 100% reliable for indicating a site for pleural decompression within an accepted 'safe zone', that is, 4th to 6th ICSs. This was measured by clinical examination from the 2nd ICS palpation and not confirmed by X-ray.[17] In our paediatric population however, we found that an age-based adjustment was required in children aged ≥4 years to improve the performance of the MAP technique, and elevate its accuracy for siting pleural decompression within this 'safe zone' above 90%. This age-based adjustment, the MAPPAED rule, stipulates that in children aged ≥4 to ≤18 years, the pleural cavity should be decompressed via the ICS one higher (more cranial) than that indicated by the MAP. Children aged <4 years should have pleural decompression via the ICS indicated the MAP technique without adjustment.

Not only does the MAPPAED rule improve the accuracy of selecting an appropriate site for pleural decompression, it also addresses the well-documented tendency and risks of pleural decompression via a site lower (more caudal) than the 'safe zone'. A 2005 study tested whether or not junior doctors could indicate on a photograph a safe site for ICD insertion. Of 55 junior doctors surveyed, 45% incorrectly indicated a site outside the 'triangle of safety', with 78% of those in error choosing a site which was lower (more caudal) than the 'triangle of safety'.[14] Incorrect entry at a site lower that this zone of safety is at risk of iatrogenic injuries to the diaphragm, stomach, colon, spleen and kidney.[19] Correct use of the MAP technique in children with the MAPPAED rule would substantially ease the cognitive burden on clinicians tasked with emergency pleural decompression, and protect already severely injured children from the super-added insult of iatrogenic visceral injuries and other procedural complications.

The MAP and MAPPAED rule will make a simple addition to the existing Rule of 4 concept[20] which aides to ease the cognitive and practical challenges of thoracostomy or ICD in injured children (Fig. 5).

Are children's arms and chests just little adult arms and chests?

In medicine, it is often remarked that 'children are not just little adults'.

Figure 5. *The rule of 4's: an aide memoire to guide safe and effective decompression of the pleural cavity and insertion of a chest drain in paediatric trauma: (i) 4 steps in a 'good plan'; (ii) 4th (or 5th) ICS as the basis for siting a 'good hole'; (iii) 4× uncuffed endotracheal tube size (4× [age/4 + 4]) to select a 'good tube'; (iv) 4 cm mark to make a 'good stop' and so ensure the tube is in far enough, but not too far.*

This sentiment is a key driver for the initiation of this study, as it could not be assumed that the reliable performance of the MAP technique observed in adults would also apply for children. Given our finding that the MAP technique was less reliable in some children and the importance of the MAPPAED rule to restore this reliability, we have reflected whether age-based changes in the anthropometry of the arm and chest wall may be underpinning these findings.

The (upper) arm length, measured as the distance from the shoulder to the elbow, increases in linear fashion with the age of the child to reach adult length by 18–19 years of age. Studies measuring upper arm length in large numbers of 'normal' children provide a good understanding of the natural growth trajectory of the arm.[21,22] These studies, based on more than 20 000 subjects, report mean upper arm lengths of: 12.3 cm at 2–5 months, 18.5 cm at 2 years, 35.8 cm at 18 years and 37.2 cm at 19 years.[21,22]

The growth trajectory of the thoracic cage is less well documented and is more complex. The thoracic cage growth is not linear, rather is typified rapid growth in the early years of life, which slows until a notable deceleration at 10–11 years and achievement of adult dimensions by 14–15 years of age.[23] Adding complexity to this non-linear trajectory, growth patterns of the upper thoracic (ribs 1–6) and lower thoracic (ribs 7–12) cage differ.[23] These distinct patterns may reflect differences in ontogeny[24] and/or muscle group insertion[25] between the upper and lower thorax. Interestingly for our considerations of the MAP technique, the basis for the association between a distinct upper thoracic growth pattern and ontogeny is suggested to be its relationship to lung and upper limb growth.[24]

Taken together, the linear relationship between (upper) arm length and age, non-linear relationship between thoracic cage growth and age, and differential upper and lower thoracic growth may provide explanation and justification for the age-based adjustment recommended by our findings, the MAPPAED rule. In the early years of life, for example before 4 years of age, more rapid growth of the thoracic cage appears to allow this growth to keep pace with the linear increase in arm length, sustaining the clinically relevant correlation between the MAP and 'safe zone' for pleural decompression (4th, 5th and 6th ICSs). As this thoracic growth rate slows but (upper) arm length continues in linear fashion the MAP will be brought into a progressively more caudal relationship on the chest wall, such that pleural decompression within the 'safe zone' requires the clinician to enter one ICS higher (more cranial) for children aged 4 years and above. Finally, as the child reaches the end of adolescence and adult dimensions for arm length and thoracic cage growth are reached, the adult relationship between MAP and thoracic cage is achieved, with the expected high reliability of the MAP technique as per Bing *et al.*[17]

Easing the procedural burden, including pre-hospital

Although not measured in this study, we noted that the MAP technique was time efficient and easy to perform, and so well suited for use in the pressured context of trauma resuscitation. The children participating in this study, had the MAP technique performed in both resuscitative and non-resuscitative medical contexts. Even in the resuscitative setting, there were no reports that the MAP measurement interfered with or delayed the child's other medical management. This ease of application for the MAP technique in children is welcome, not only in the paediatric trauma resuscitation room, but also in pre-hospital environments. A recent review of adult and paediatric trauma patients audited 179 thoracostomies performed by suitably-trained paramedics over a 3-year period. In this series, pre-hospital thoracostomy in adults and children was associated with a low rate of major complications.[10] Given the concerns regarding the efficacy of needle thoracocentesis, these authors recommend thoracostomy as the preferred approach for pre-hospital pleural decompression. With specific reference to children undergoing pre-hospital thoracostomy and/or ICD insertion, the use of the MAP technique and MAPPAED rule could make a positive safety-focused addition to training for, and performance of, these pre-hospital procedures.

Clinicians who performed the MAP technique in children varied in grades: from interns through to consultants. This suggests that measuring and using the MAP, and the age-based application of the MAPPAED rule, to determine a safe site for pleural decompression in children is easily taught, and within the expected skill mix of clinicians of all grades.

Limitations

Despite our best efforts to assess the utility of the MAP technique in wide range of children and ages, the ability to extrapolate our findings to the paediatric population as a whole may be limited by (i) small sample size (only 712 measurements); and (ii) the children participating in our study were uninjured, for reasons of study design and ethical considerations.

Conclusion

MAPPAED rule: in children aged 4 years or more, use the MAP and go up one ICS to hit the 'safe zone'. In children under 4 years, use the MAP.

In summary, the MAP technique is a reliable approach to determining a safe site for pleural decompression in children, albeit it requires an age-based adjustment, the MAPPAED rule, which correlates with changes to arm and chest anthropometry during childhood growth.

This will rapidly and easily identify a site within the 'safe zone' (4th to 6th ICSs) in 9 out of 10 children. Thus, the findings and application of this study represents an advance in paediatric trauma care that will increase efficiency and reduce morbidity of thoracostomy and intercostal chest tube insertion. We will now proceed to validate the MAPPAED rule with further study. The reality that the MAP technique is not 100% reliable in children reminds clinicians of the need to stay engaged in the safety and steps of their procedure, rather than relying solely on this guide to site pleural decompression. Checking is a good final step, even in an emergency.

Acknowledgements

The authors would like to thank and acknowledge those clinicians and colleagues in all four participating centres, who assisted in recruitment and engagement with this study. This study was generously supported by a €10,000 Seed Funding Grant from Children's Health Ireland (CHI) at Temple Street, Dublin, Ireland for consumables, video and media education. Additional consumable expenses were provided by the Surgical Research Group, Murdoch Children's Research Institute, Melbourne, Victoria, Australia. WJT is generously supported by the RCH Foundation, Melbourne, Victoria, Australia. Open access publishing facilitated by The University of Melbourne, as part of the Wiley - The University of Melbourne agreement via the Council of Australian University Librarians.

Competing interests

None declared.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Australian Institute of Health and Welfare. *Australia's children (Cat. no. CWS 69)*. 2020. [Cited 28 Aug 2021.] Available from URL: https://www.aihw.gov.au/reports/children-youth/australias-children
2. Mitchell RJ, Curtis K, Foster K. A 10-year review of child injury hospitalisations, health outcomes and treatment costs in Australia. *Inj. Prev*. 2018; **24**: 344–50.
3. Peden MM. *World Report on Child Injury Prevention*. Geneva: World Health Organization; New York, NY: United Nations Children's Fund; 2008. Available from URL: http://www.who.int/violence_injury_prevention/child/injury/world_report/en/index.html, http://whqlibdoc.who.int/publications/2008/9789241563574_eng.pdf
4. UNICEF. Child and adolescent injuries. [Cited 28 Aug 2021.] Available from URL: https://www.unicef.org/health/injuries
5. The Trauma Audit & Resrach Network (TARN). Severe injury in children 2017–2018. 2020. [Cited 28 Aug 2021.] Available from URL: https://www.tarn.ac.uk/content/downloads/3572/Severe%20Injury%20in%20Children%202017-2018.pdf
6. Quinn N, Palmer CS, Bernard S, Noonan M, Teague WJ. Thoracostomy in children with severe trauma: an overview of the paediatric experience in Victoria, Australia. *Emerg. Med. Australas*. 2020; **32**: 117–26.
7. Kuckelman J, Derickson M, Phillips C *et al*. Evaluation of a novel thoracic entry device versus needle decompression in a tension pneumothorax swine model. *Am. J. Surg*. 2018; **215**: 832–5.
8. Laan DV, Vu TD, Thiels CA *et al*. Chest wall thickness and decompression failure: a systematic review and meta-analysis comparing anatomic locations in needle thoracostomy. *Injury* 2016; **47**: 797–804.
9. Fitzgerald M, Mackenzie CF, Marasco S, Hoyle R, Kossmann T. Pleural decompression and drainage during trauma reception and resuscitation. *Injury* 2008; **39**: 9–20.
10. Hannon L, St Clair T, Smith K *et al*. Finger thoracostomy in patients with chest trauma performed by paramedics on a helicopter emergency medical service. *Emerg. Med. Australas*. 2020; **32**: 650–6.
11. Waydhas C, Sauerland S. Pre-hospital pleural decompression and chest tube placement after blunt trauma: a systematic review. *Resuscitation* 2007; **72**: 11–25.
12. Australian and New Zealand Committee on Resuscitation (ANZCOR). *ANZCOR Guideline 11.10.1: Management of Cardiac Arrest Due to Trauma*. Melbourne: Australian Resuscitation Council, 2016. Available from URL: https://resus.org.au/wpfb-file/anzcor-guideline-11-10-1-als-traumatic-arrest-27apr16-pdf/
13. Vassallo J, Nutbeam T, Rickard AC *et al*. Paediatric traumatic cardiac arrest: the development of an algorithm to guide recognition, management and decisions to terminate resuscitation. *Emerg. Med. J*. 2018; **35**: 669–74.
14. Griffiths JR, Roberts N. Do junior doctors know where to insert chest drains safely? *Postgrad. Med. J*. 2005; **81**: 456–8.
15. Kong VY, Oosthuizen GV, Sartorius B, Keene C, Clarke DL. An audit of the complications of intercostal chest drain insertion in a high volume trauma service in South Africa. *Ann. R. Coll. Surg. Engl*. 2014; **96**: 609–13.
16. Carter P, Conroy S, Blakeney J, Sood B. Identifying the site for intercostal catheter insertion in the emergency department: is clinical examination reliable? *Emerg. Med. Australas*. 2014; **26**: 450–4.
17. Bing F, Fitzgerald M, Olaussen A *et al*. Identifying a safe site for intercostal catheter insertion using the mid-arm point (MAP). *J. Emerg. Med. Trauma Acute Care* 2017; https://doi.org/10.5339/jemtac.2017.3.
18. Sethuraman KN, Duong D, Mehta S *et al*. Complications of tube thoracostomy placement in the emergency department. *J. Emerg. Med*. 2011; **40**: 14–20.
19. Kong VY, Clarke DL. The spectrum of visceral injuries secondary to misplaced intercostal chest drains: experience from a high volume trauma service in South Africa. *Injury* 2014; **45**: 1435–9.
20. Teague WJ, Amarakone KV, Quinn N. Rule of 4's: safe and effective pleural decompression and chest drain insertion in severely injured children. *Emerg. Med. Australas*. 2019; **31**: 683–7.
21. Fryar CD, Gu Q, Ogden CL. Anthropometric reference data for children and adults: United States, 2007–2010. *Vital Health Stat 11*. 2012: 1–48.
22. Snyder RG, Schneider LW, Owings CL, Reynolds HM, Golomb DH, Schork MA. *Anthropometry of Infants, Children and Youths to Age 18 for Product Safety Design. Final Report*. Ann Arbor, MI: Highway Safety Research Institute, 1977.
23. Bastir M, Garcia Martinez D, Recheis W *et al*. Differential growth and development of the upper and lower human thorax. *PLoS One* 2013; **8**: e75128.
24. Bastir M. A systems-model for the morphological analysis of integration and modularity in human craniofacial evolution. *J. Anthropol. Sci*. 2008; **86**: 37–58.
25. Ward ME, Ward JW, Macklem PT. Analysis of human chest wall motion using a two-compartment rib cage model. *J. Appl. Physiol. (1985)* 1992; **72**: 1338–47.

Supporting information

Additional supporting information may be found in the online version of this article at the publisher's web site:

Video S1. The steps of the Mid-Arm Point technique.