Resuscitation 121 (2017) 9–33

Contents lists available at ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Review

The accuracy of the Broselow tape as a weight estimation tool and a drug-dosing guide – A systematic review and meta-analysis

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ARTICLE INFO

Article history:
Received 29 May 2017
Received in revised form 31 August 2017
Accepted 23 September 2017

Keywords:
Broselow tape
Paediatric weight estimation
PAWPER tape
Mercy method
Resuscitation aid

ABSTRACT

Aims: The Broselow tape is widely used as a weight-estimation device and drug-dosing guide aid, but concerns about its accuracy and its efficacy have emerged in the last decade. The aim of this study was to systematically review the literature to analyse the accuracy of the Broselow tape as a weight estimation device and review evidence of its utility as a drug-dosing guide.

Methods: This was a MOOSE-driven systematic review and meta-analysis, which focused on studies evaluating the accuracy of the Broselow tape and studies reviewing its use as a drug-dosing aid.

Main results: The tape has undergone substantial changes over the years, but there was no evidence to show that the changes have improved weight-estimation performance. The weight-estimation accuracy of the tape was suboptimal in all populations, with just over 50% of children receiving an estimation within 10% of their actual weight. The overestimation of weight in low- and middle-income countries was often extreme. This indicated a significant potential for potentially harmful medication errors. The limited available evidence on the value of the tape as a drug-dosing guide indicated that the tape was frequently used incorrectly and contained insufficient information to function without additional resources.

Conclusions: The Broselow tape lacked sufficient accuracy as a weight estimation and drug-dosing tool when compared to other available techniques. In addition, the Broselow tape contains insufficient drug-dosing information to function as a complete resuscitation aid without additional material. The frequent rate of incorrect usage of the tape indicated that appropriate training with the tape is mandatory to reduce errors.

1 Introduction

The Broselow tape has not been the subject of systematic review or meta-analysis previously. This review is important because a knowledge and understanding of the tape, its different functions, its strengths and its weaknesses will assist its potential users to decide whether it is the best weight estimation system and drug-dosing guide for their population and their particular needs. It will also assist decision-makers in the Emergency Department and Emergency Medical Services to develop appropriate evidence-based approaches to emergency weight estimation and emergency drug dosing in children.

The Broselow tape was developed primarily as a tool to facilitate the delivery of rapid, appropriate and safe treatment during emergencies, but most of the research published on the tape has focused on the accuracy of the weight estimation [1–3]. The Broselow tape has not been without controversy: some experts have suggested that the Broselow tape, because of its underestimation of weight in high-income countries, would lead to the "under-resuscitation of children" and that it might even no longer be relevant [4,5]. At the other end of the habitus spectrum, there is also evidence that the tape, especially in its latest edition, substantially overestimates the weight of children in populations from low- and middle-income countries, often to a potentially dangerous degree [6–8]. Since the Broselow tape is still widely used across the world as a weight-estimation tool,an understanding of its accuracy, especially when

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; APLS, Advanced Paediatric Life Support formula; ARC, Australian Resuscitation Council formula; BG, Best Guess formula; BMI, body mass index (kg/m^2); BT, Broselow tape; DWEM, devised weight-estimating method; ED, emergency department; EMS, emergency medical services; EPLS, European life support formula; FE, fixed effects; HCP, healthcare provider; IBW, ideal body weight; IQR, interquartile range; IV, inverse variance; MAC, mid-arm circumference; MPE, mean percentage error; MT, mercy tape; NCHS, National Centre for Health Statistics; PAWPER, paediatric advanced weight prediction in the emergency room; PW10, percentage of estimates within 10% of actual weight (%); PW20, percentage of estimates within 20% of actual weight (%); RE, random effects; TBW, total body weight; TJ, Traub-Johnson formula; TK, Traub-Kichen formula.

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https://doi.org/10.1016/j.resuscitation.2017.09.026
0300-9572/

compared to other, newer weight estimation systems, would be useful.

The Broselow tape's effectiveness as a resuscitation aid to provide critical drug-dosing information has also been questioned [9,10]. This raises interesting new uncertainties. This is significant because some experts, and advanced life support courses, advocate the use of "a body length tape with pre-calculated doses", which may, in fact, not be compatible with best evidence-based practice [11].

Therefore, to minimise the potential for medication errors during the emergency management of children, it would be valuable to conduct a careful "re-examination of the accuracy of the Broselow tape" [12].

The objectives of this review were:

- To review the available evidence on the accuracy of the Broselow tape as a weight-estimation instrument in different populations and perform a *meta*-analysis on this data.
- To review the available evidence on the efficacy of the tape as a drug-dosing guide during the management of paediatric emergencies.

2 Methods

2.1 Systematic review and meta-analysis

This study followed the guidelines for meta-analyses and systematic reviews of observational studies (MOOSE-guidelines).

2.2 Search strategy

Online databases (MEDLINE, SCOPUS, Science Direct and Google) were searched for appropriate studies, published between January 1986 and January 2017, using the search terms: "paediatric weight estimation", "weight estimation children", "resuscitation aid" and "Broselow tape". Citations from reference lists, abstracts, conference presentations and unpublished material were also scrutinised to identify articles for potential inclusion.

2.3 Study selection and eligibility criteria

All studies that appraised, reviewed or discussed the Broselow tape were separately considered for inclusion by two investigators (MW and LG). There were two areas of interest: the accuracy of the Broselow tape as a weight estimation system and the Broselow tape as a medication-dosing guide (see Fig. 1). Each study was graded for quality of evidence using a modified Newcastle-Ottawa scale (see Supplementary Table 1) and for risk of bias. Evaluated studies were downgraded if there were significant methodological weaknesses (e.g. length data converted to Broselow tape weight estimate), if data presentation was incomplete and if performance outcome data was not appropriately converted to percentage or logarithmic format. Studies were excluded from the meta-analysis if they did not contain appropriate data describing bias and precision (mean percentage error plus any appropriate measure of variance) *or* data describing accuracy (percentages of weight estimations accurate to within 10% of actual weight).

2.4 Data abstraction and analysis

Mean percentage error (MPE) with the 95% limits of this error were used to evaluate the bias and precision of the Broselow tape. The percentage of weight estimations within 10% of actual weight (PW10) was used to evaluate the accuracy of the Broselow tape. Standard statistics for meta-analysis of method-comparison studies were used, but the included studies showed a significant amount of within-study variance as well as between-study variance that needed to be considered [13]. Two methods of representing the pooled data were employed: a fixed effects model weighted by inverse variance (method 1); and a random effects model (method 2). The sizeable variance between studies, the inclusion of several large database studies with substantial within-study variance and the heterogeneity between populations meant that the random effects models were preferred for most analyses. Where more than one study contained data on the Broselow tape as well as other weight-estimation methodologies, these were directly compared using accuracy outcomes in a random-effects, inverse variance-weighted model.

2.5 Risk of bias within and across studies

Many of the studies were at risk of performance bias because the measuring personnel were not blinded during the execution of weight estimation (e.g. the use of the Broselow tape) and there was similarly a risk of detection bias, as the outcome assessors were not blinded, but, since most of the data were in simple, objective, numerical form, this lack of blinding was believed unlikely to cause significant bias. Reporting bias (or publication bias) was minimised by including all available methodologically sound studies in the review, published or not. Methodological causes of potential bias were common (e.g. the Broselow tape was not actually used in many studies, but weight-estimates were instead generated from length data), but these were individually assessed and rated according to the level of risk of systematic bias. Evaluation of pooled data with and without studies of uncertain risk yielded similar outcomes. Further evaluation of data with and without the inclusion of the very large, retrospective database studies also produced similar outcomes, which suggested a negligible bias caused by these studies. Studies with high risk of bias were excluded from the meta-analysis, however. Table 1 provides a descriptive summary of the studies included in this review. The raw data from the included studies is shown in Supplementary Table 2.

The quality of the evaluated studies was rated according to the prescribed MOOSE criteria, including rationale for the selection of participants, assessment of confounding factors, assessment of study quality, including blinding of quality assessors, assessment of heterogeneity, description of statistical methods and provision of appropriate tables and graphics.

2.6 Sensitivity analysis

Since the outcomes between study populations from high-income and low- and middle-income countries were markedly different, these studies were also evaluated within different categories. While the prevalence of obesity may also be significant in low- and middle-income countries (e.g. 24% in Botswana, 14% in Sudan), the real difference between high-income and low- and middle-income countries may be the prevalence of underweight children rather than obesity only [14]. Three categories were considered for the subgroup analysis, based on the prevalence of underweight children in that country or region: Category I – low (<2%) prevalence of underweight children (high-income countries); Category II – medium (2–8%) prevalence of underweight (generally middle-income countries e.g. Mexico, Thailand, Iran, parts of South Africa); and Category III – high (>8%) prevalence of underweight (generally low- and middle-income countries e.g. India, most African countries).

2.7 Subgroup analysis

Wherever possible, subgroup data, by age or weight, that were presented in each study were included and evaluated in the overall meta-analysis strategy.

Table 1
Studies included in the review. Basic information is shown, including an assessment of risk of bias and the Newcastle-Ottawa Scale star-rating of study quality (maximum score of 10 stars). The first part of the table (1a) shows studies with weight estimation data that were evaluated for inclusion in the quantitative analysis of weight-estimation accuracy. The second part of the table (1b) shows the studies included for the assessment of the accuracy of the Broselow tape as a resuscitation and drug-dosing aid or for qualitative data.

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Lubitz 1988 [2]	937	USA	P	0 to 12yrs	Broselow tape	Yes	**Main Results:** This was the original study of the Broselow tape. The Broselow tape was better than healthcare provider guesses and had similar accuracy to DWEM. Accuracy of Broselow tape fell off sharply in children >25 kg. The authors recommended that an assessment of body habitus should be considered in children >25 kg **Weaknesses:** No formal, prospective comparison with other methodologies or indication of desirable accuracy. ★★★★★★ Risk of bias: low
Hughes 1990 [3]	139	UK	P	0 to 10yrs	Broselow tape, healthcare provider guesses	No	**Main Results:** This was the first validation study of the Broselow tape in the UK. The Broselow tape performed substantially better than nurses' guesses. **Weaknesses:** Small sample size. Limited statistics with incomplete data. ★★★★ Risk of bias: high (incomplete data and/or statistical analysis)
Dearlove 1999 [15]	50	UK	P	1 to 16yrs	Parental estimates, Broselow tape, EPLS, Argall	Yes	**Main Results:** The Broselow tape performed best, far better than parental estimates and age-based formulas. A target of 10% accuracy was considered appropriate for children. **Weaknesses:** Limited statistical analysis and very small sample size. ★★★★ Risk of bias: low
Kun 2000 [16]	909	Hong Kong	P	0 to 12yrs	Broselow tape	Yes	**Main Results:** The Broselow tape was most accurate in children 10–25 kg. Adjustment for habitus recommended by authors. Objective assessment of the accuracy of Broselow tape outside of the 10–25 kg range showed that it was actually moderate and not as good as the authors suggest. **Weaknesses:** Incorrect interpretation of some statistics. Broselow tape version not reported. ★★★★ Risk of bias: low
Black 2002 [17]	495	Australia	P	0 to 18yrs	EPLS, Broselow tape, DWEM, Oakley, TJ, TK	Yes	**Main Results:** The Broselow tape and DWEM were more accurate than formulas. These methods should be used if weighing not possible. The EPLS was the worst performer but there was poor accuracy of all systems. Good reproducibility of assessment of body habitus for the DWEM. **Weaknesses:** Limited and incomplete statistics. Broselow tape version not reported. ★★★★ Risk of bias: low
Hofer 2002 [18]	585	Switzerland	R	6mo to 11yrs	Broselow tape	Yes	**Main Results:** The Broselow tape was moderately accurate but underestimated weight in older children. Nearly 25% of sample excluded because they were too tall for the tape. **Weaknesses:** Broselow tape not actually used and version not reported. Incomplete reporting of data. ★★★★ Risk of bias: low
Argall 2003 [19]	300	UK	P	1 to 10yrs	EPLS, Broselow tape	No	**Main Results:** Both methods performed poorly and worsened with increasing age. Difficult to draw any conclusions from this study because of incomplete date presentation, but the Broselow tape was marginally better than the formula. The authors suggested that methods of weight estimation are not keeping up with increasing obesity. **Weaknesses:** Broselow tape version not reported. Incomplete statistical reporting made interpretation difficult. ★★★★ Risk of bias: unknown
Potier 2003 [20]	–	–	–	–	EPLS, Broselow tape	No	**Main Results:** this was a non-systematic mini- PICO analysis. The EPLS "may" be losing accuracy with increasing obesity; Broselow tape "may indeed be" more accurate. **Weaknesses:** Limited qualitative-only evaluation. No comment on acceptable degree of accuracy. ★★ Risk of bias: high
Theron 2005 [20]	909	New Zealand	P	1 to 10yrs	EPLS, Shann, Leffler, Oakley, Broselow tape	Yes	**Main Results:** Formulas and the Broselow tape underestimated the weight of Pacific Island and Maori children. The Broselow tape was the best performer of the systems tested, despite the fact that the authors reported the contrary. **Weaknesses:** Broselow tape version not reported. Limited and incomplete statistics. ★★★★ Risk of bias: low

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Nieman 2006 [5]	7813	USA	R	0 to 12yrs	Broselow tape	Yes	**Main Results:** One third of children had inaccurate weight estimations. Surprisingly, the 1998 tape performed better than the 2002 tape. The authors suggested that a measurement of obesity (e.g. mid-arm circumference) should be added to Broselow tape to increase accuracy. Broselow tape version 1998 and 2002A used. The study population BMI was 16.8 kg/m^2. Good statistics. **Weaknesses:** Broselow tape not actually used. Nearly 7% of sample excluded because they were too tall for the tape. ★★★★★★★ Risk of bias: low
Varghese 2006 [21]	500	India (Cat III)	P	1 to 12yrs	Argall, EPLS, Nelson, Broselow tape	No	**Main Results:** Formulas overestimated weight in this low- and middle-income country study. The Broselow tape was the most accurate. More than half the study population was under 6 months of age and only 8% >5yrs. **Weaknesses:** Limited statistical reporting and data analysis made findings difficult to interpret. Age-range of sample very skewed to younger children. ★★★ Risk of bias: high
Du Bois 2007 [22]	400	USA	P	0 to 19yrs	Broselow tape, DWEM	Yes	**Main Results:** The DWEM performed better than the Broselow tape, but both systems underestimated weight, especially in children >20 kg. There was good inter-rater reliability for habitus assessment. Although the performance of DWEM was better than Broselow tape, both systems performed poorly. **Weaknesses:** Limited data and statistics. Broselow tape version not reported. Statistically inappropriate accuracy target suggested (bias confused with accuracy). ★★★★★★ Risk of bias: low
Hashikawa 2007 [23]	1207	USA	R	0 to 12yrs	Broselow tape	Yes	**Main Results:** Approximately 60% accuracy of colour zone assignment (i.e. accurate drug dosing). Weight was underestimated in obese and older children. The rising prevalence of obesity blamed for poor performance. Broselow tape version 2002B. The average study population BMI was 17 kg/m^2. **Weaknesses:** Broselow tape not actually used. Assessment of correct zone assignment only, weight not measured. Limited and incomplete statistics. Risk of bias: low
Im 2007 [24]	454	Korea	P	–	Broselow tape	No	**Main Results:** The Broselow tape was accurate in children of normal weight-for-length. Only children falling within 3rd to 97th weight-for-height centiles were included. Very young study population. Broselow tape only recommended by authors for "normal-growth" children <20 kg in weight and <120 cm in height. **Weaknesses:** poor methodology and limited statistics. Conclusions not justified or supported by findings. ★★★ Risk of bias: high
Jang 2007 [25]	665	Korea	R	0 to 12yrs	Broselow tape	Yes	**Main Results:** The Broselow tape was reasonably accurate in this population, but less so in children >25 kg. There was an overall underestimation of weight and the performance was not very good, although on par with most other studies. **Weaknesses:** Broselow tape not actually used and version not reported. Limited and incomplete statistics. ★★★★ Risk of bias: low
Krieser 2007 [26]	410	Australia	P	1 to 10yrs	Parental estimates, Broselow tape, BG, Argall, EPLS	Yes	**Main Results:** Parental estimates performed best, followed by the Broselow tape. Only 11% of parents could not provide an estimate. Formulas performed much worse than other methods. Study population BMI 17.1 kg/m^2. **Weaknesses:** Multiple papers on same data. Broselow tape not actually used. Broselow tape version not reported. Incomplete statistical analysis. ★★★★★ Risk of bias: low
Patel 2007 [27]	360	USA	P	1mo to 10yrs	Parental estimates, EPLS, Broselow tape	No	**Main Results:** Abstract. Parental estimates performed best, then Broselow tape, then EPLS. Conclusions based on correlation and rudimentary statistical analysis**. Weaknesses:** Limited data and statistics presented. Findings unreliable and hard to interpret. ★★★ Risk of bias: high

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Zikos 2007 [28]	360	USA	P	1mo to 10yrs	Parental estimates, EPLS, Broselow tape	No	**Main Results:** Virtually identical abstract and data to Patel 2007. ★★★ Risk of bias: high
Ramarajan 2008 [29]	548	India (Cat III)	P	0 to 12yrs	Broselow tape	Yes	**Main Results:** The Broselow tape overestimated weight by >10% in Indian children over 10 kg. A correction factor was developed, but not validated. One of the earliest studies to show overestimation of weight by Broselow tape. **Weaknesses:** Broselow tape version not reported. Incomplete statistical analysis and data presentation. ★★★★★★★ Risk of bias: low
Zink 2008 [30]	127	USA	P	0 to 17yrs	Parental estimates, healthcare provider guesses, DWEM, Broselow tape	No	**Main Results:** The authors claimed that the Broselow tape and DWEM were the least accurate methods. No conclusions could be drawn from this study because of the defective methodology. **Weaknesses:** The data appears to favour healthcare provider and parent guesses, but the statistical methodology was flawed. ★★ Risk of bias: high
Anstett 2009 [31]	545	Ireland	R	–	Broselow tape	Yes	**Main Results:** Abstract. The Broselow tape was often inaccurate and tended to underestimate weight, but actually performed better in this study than in many other studies. **Weaknesses:** Broselow tape version not reported. Broselow tape not actually used. ★★★★★★ Risk of bias: low
Cattamanchi 2009 [32]	15000	India (Cat III)	P	2mo to 12yrs	Broselow tape	Yes	**Main Results:** Abstract. Very large prospective study. The Broselow tape performed well, especially in children <10 kg but underestimated all others, especially in children >18 kg. The authors recommended a new version of Broselow tape for Indian children because of underestimation of weight. **Weaknesses:** Broselow tape version not reported. Incomplete statistical analysis and some misinterpretation of data. ★★★★★★★ Risk of bias: low
Cattermole 2009 [33]	1368	Hong Kong	P	1 to 12yrs	MAC formula, Broselow tape, foot length	No	**Main Results:** Abstract. Estimates of weight can be based on mid-arm circumference. A special colour-coded MAC tape could be produced to aid drug dosing. The authors recommended a habitus modified use of Broselow tape. Broselow tape performed better in younger children, MAC better in older children. **Weaknesses:** No data presented. ★★★ Risk of bias: high
So 2009 [34]	1011	USA	P	0 to 10yrs	Broselow tape, Leffler, Theron	Yes	**Main Results:** Broselow tape most accurate weight estimation method with best accuracy in normal BMI children. Study population BMI 17.8 kg/m^2. A new formula developed, but not tested. **Weaknesses:** Poor statistical analysis and interpretation of data (bias mistaken for accuracy). Broselow tape not actually used and Broselow tape version not reported. ★★★★ Risk of bias: low
Stewart 2009 [35]	475	Australia	P	0 to 10yrs	Broselow tape	Yes	**Main Results:** Masters dissertation. The best performance of Broselow tape was between 10 and 25 kg but it was very inaccurate in children >25 kg. More accurate than age-based formulas, however. Good statistics. **Weaknesses:** Broselow tape version not reported. ★★★★★★★★ Risk of bias: low
Yamamoto 2009 [36]	542	Hawaii	P	–	Broselow tape, novel habitus-specific equation	No	**Main Results:** Adding body habitus data to length increases accuracy of weight estimation. Overweight children were preferentially selected in this study **Weaknesses:** Atypical statistical analysis – limited conclusions can be drawn from data. Data unable to be imputed. Broselow tape version not reported and Broselow tape not actually used. ★★★ Risk of bias: high

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Casey 2010 [37]	1426	Australia	P	0 to 14yrs	EPLS, BG, Broselow tape	Yes	**Main Results:** BG was accurate in children 1–4yrs of age. The EPLS formula was the least accurate of all methods. The authors recommend that the accuracy and ease of use of the Broselow tape mandates its use in the ED and pre-hospital. The authors' suggestions that the BG was more "accurate" than the Broselow tape is misleading: the Broselow tape actually significantly outperformed the BG formula. BMI 17.9 kg/m^2 in study population. **Weaknesses:** Limited and incomplete statistics. Broselow tape not actually used and Broselow tape version not reported. ★★★★ Risk of bias: low
Cattermole 2010 [38]	1370	Hong Kong	P	0 to 11yrs	EPLS, Broselow tape, MAC formula	Yes	**Main Results:** MAC formula outperformed Broselow tape in children >5yrs. MAC was actually only more accurate in children 9 to 11yrs who were too tall for the Broselow tape. Poor accuracy of all systems demonstrated. **Weaknesses:** Broselow tape not actually used and 1998 edition values used. The reference for desired accuracy targets not based on evidence. ★★★★★★★ Risk of bias: low
Lulic 2010 [39]	209	Croatia	P	0 to 14yrs	EPLS, Argall, BG, Luscombe, Broselow tape	Yes	**Main Results:** Abstract. The Broselow tape was more accurate than age-based formulas but tended to slightly underestimate weight. None of the systems estimated weight with an acceptable degree of accuracy. **Weaknesses:** Broselow tape version not reported. Limited statistical analysis and data presentation. ★★★★★★ Risk of bias: low
Bourdeau 2011 [40]	243	Canada	R	1 to 10yrs	Broselow tape	Yes	**Main Results:** First Nations children selected with high incidence of obesity in this population. The Broselow tape was not accurate in First Nations children and may need to increase weight estimates by 12%. The authors comment that although ideal method of dosing still unknown, it is best practice to eliminate any possible contributing inaccuracies. Broselow tape did not perform equally well in all ethnic/population groups. **Weaknesses:** Incorrect use of some statistics. Broselow tape not actually used and Broselow tape version not reported. ★★★★★★ Risk of bias: low
Geduld 2011 [41]	2832	South Africa (Cat II)	P	0 to 10yrs	EPLS, Luscombe, BG, Broselow tape	Yes	**Main Results:** Data from a poor community in South Africa. The Broselow tape and EPLS formula were most accurate in this population. The accuracy of EPLS formula was the best ever reported while that of the Broselow tape was on par with other reports. Only 4% of children excluded as too tall for the tape. The authors suggest that careful titration of drugs and use of clinical judgment most important in using medications safely and whether the differences in accuracy of any weight estimation system are likely to affect outcomes. **Weaknesses:** Broselow tape not actually used and Broselow tape version not reported. ★★★★★★★ Risk of bias: low
Knight 2011 [42]	657	USA	R	–	Broselow tape	Yes	**Main Results:** Broselow tape 2007 B used. The Broselow tape performed poorly, potentially leading to under-resuscitation in all weight categories, especially in younger children. Drug doses correct in only about 50% of cases. Consensus opinion required whether to use ideal body weight or total body weight during resuscitation. There was a high incidence of obesity in the study population. **Weaknesses:** Broselow tape not actually used. Limited statistical analysis with no direct assessment of accuracy of weight estimation. ★★★★ Risk of bias: low

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Rosenberg 2011 [43]	372	USA	P	0 to 14yrs	Healthcare provider guesses, Broselow tape	Yes	**Main Results:** Broselow tape 2007 B used. The Broselow tape was better than guesses by doctors, but not in obese children. Doctors assessed habitus poorly. Ideal body weight. Nearly 35% of study population was obese or overweight. Mean BMI 17.4 kg/m^2. It was a reflection of how poorly the Broselow tape performed in obese children that doctor estimates were better; the overall findings of Broselow tape accuracy similar to other studies. **Weaknesses:** Incomplete data presentation. Incorrect usage of some statistics. ★★★★★★ Risk of bias: low
Abdel-Rahman 2012 [44]	1938	USA	R	0 to 16yrs	EPLS, ARC, Argall, BG, Broselow tape, Cattermole, Leffler, Luscombe, Nelson, Shann, TJ, TK, Mercy method	Yes	**Main Results:** The Mercy method performed significantly better than the age-based, length-based and MAC-based systems. This was the original development and validation study of the Mercy method. Good mix of overweight children, but few underweight kids in sample. The Broselow tape was unable to be used in more than one third of the sample (too tall for the tape). **Weaknesses:** Broselow tape not actually used and Broselow tape version not reported. ★★★★★★ Risk of bias: low
Heyming 2012 [45]	491	USA	P	IQR 10 to 49mo	Broselow tape EMS vs. Broselow tape ED	No	**Main Results:** The Broselow tape was an accurate tool to estimate weight. Agreement between pre-hospital personnel and ED personnel for Broselow tape weight was only 70.1%. **Weaknesses:** Most of study population was <4yrs. Incorrect use of statistics for assessing accuracy of weight estimation. Broselow tape version not reported. ★★★★ Risk of bias: high
Milne 2012 [4]	6361	Canada	R	IQR 1.6–7.7yrs	Broselow tape	Yes	**Main Results:** Broselow tape edition 2002A used. The Broselow tape was effective, although significantly underestimated weight. Similar findings in urban and rural children. The authors suggested that an error range of 30% is reasonable and that, ideally, technology should be developed to estimate weight and aid with drug dosing. **Weaknesses:** Broselow tape not actually used – data taken from anthropometric measurements. ★★★★★★ Risk of bias: low
Park 2012 [46]	124095	Korea	R	0 to 14yrs	EPLS, Shann, Leffler, Nelson, BG, Broselow tape, Park	Yes	**Main Results:** All methods underestimated weight and performed poorly, possibly because of a secular trend towards increasing obesity. The Park formula performed best and was accurate in children <1yr of age. **Weaknesses:** Limited statistical analysis and poor interpretation of bias vs. accuracy. Broselow tape was not actually used and Broselow tape version not reported. ★★★★ Risk of bias: low
Sinha 2012 [47]	118	USA	P	0 to 14yrs	Broselow tape	Yes	**Main Results:** Broselow tape weight was compared to stretcher weight. It was possible to weigh children during trauma resuscitation, but nearly 40% of children in the study could not be weighed – more often the sicker patients (the authors did not fully explain this). There was a poor performance by Broselow tape and 18% of children were too tall for the tape. **Weaknesses:** There was no validation of the accuracy of weight measured during resuscitation. Incomplete statistics and data presentation. Broselow tape version not reported. ★★★★★★ Risk of bias: low
Trakulsrichai 2012 [48]	595	Thailand (Cat II)	P	0 to 12yrs	Broselow tape, parental estimates, growth charts	Yes	**Main Results:** Family member estimation was most accurate and the Broselow tape the most accurate of other weight estimation methods. There was equal underestimation and overestimation by Broselow tape while family estimates tended to overestimate. **Weaknesses:** Incomplete statistics. Broselow tape version not reported. Risk of bias: low

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Wozniak 2012 [49]	777	Botswana (Cat III)	P	18mo to 12yrs	EPLS, Luscombe, Theron, Cattermole, Broselow tape	Yes	**Main Results:** Masters dissertation. The prediction models incorporating MAC and either tibia or ulna length performed extremely well. Age-based formulas were very inaccurate. Weight was markedly overestimated by the Broselow tape and by age-based formulas in this population with a high prevalence of HIV. **Weaknesses:** Incomplete statistics. ★★★★★★★ Risk of bias: low
Abdel-Rahman 2013 [50]	624	USA	P	0 to 16yrs	Mercy method 2D, 3D, Broselow tape	Yes	**Main Results:** Multicentre study (3) in the USA. Both 2D and 3D Mercy methods outperformed the Broselow tape although the 3D tape was significantly less accurate than the 2D method. The study population had a mean BMI of 17.3 kg/m^2. Children much older than most weight-estimation studies were included. One third of children were too tall for the tape. **Weaknesses:** Broselow tape not actually used and Broselow tape version not reported. ★★★★★★★ Risk of bias: low
Abdel-Rahman 2013 [51]	976	USA	P	0 to 16yrs	Mercy method, EPLS, Broselow tape, Luscombe, Nelson	Yes	**Main Results:** The Mercy method was accurate across a wider age range than other methods. The study population mean BMI was 17.6 kg/m^2 with very few underweight children. Inter-rater assessment was generally reasonable, but two of the raters were significantly inferior to the others. **Weaknesses:** Broselow tape not actually used and Broselow tape version not reported. ★★★★★★★ Risk of bias: low
Akabarian 2013 [52]	403	Iran (Cat II)	P	0 to 14yrs	Broselow tape, parental estimates	Yes	**Main Results:** Article in Arabic. The Broselow tape was less accurate than parental estimates, but recommended for use by the authors. Very good performance of Broselow tape compared to previous studies. **Weaknesses:** Exclusion criterion of weight >35 kg skewed the assessment of Broselow tape accuracy. Limited statistical analysis and data presentation. Broselow tape version not reported. ★★★ Risk of bias: unknown
Cattermole 2013 [53]	171	Hong Kong	P	7 to 11yrs	Broselow tape	No	**Main Results:** Selective evaluation of children who were too tall for Broselow tape. Children "too tall for the tape" do not have full adult weight – this assumption would lead to an average 30% overestimation of weight in this study. About 40% of children were too tall for the tape. Interesting data, which highlights a flaw in the Broselow tape methodology. Broselow tape was not practically useful over the age of 10. An overestimation of 30% would be unacceptable but there was no mention of desirable target. **Weaknesses:** Relatively small sample size. ★★★★★★ Risk of bias: high
Graves 2013 [54]	37114	USA	R	0 to 14yrs	EPLS, new APLS, BG, Luscombe, Broselow tape	Yes	**Main Results:** The Broselow tape 2007 B was used. The new APLS formula was best for infants, BG best for older children. The Broselow tape placed up to 60% of children in the wrong zone. Despite criticisms of Broselow tape, it outperformed the formulas in every analysis. This study had some of the poorest performances of aged-based formulas in any study. A calculation of the study population BMI was 18–22 kg/m^2. **Weaknesses:** Incomplete and poorly interpreted statistics. Broselow tape not actually used. ★★★★★★ Risk of bias: low
House 2013 [55]	967	Kenya (Cat III)	P	0 to 14yrs	Broselow tape, EPLS, Nelson	Yes	**Main Results:** The Broselow tape 2007 B was used. The Broselow tape performed better than the formulas and a measure of habitus assessment (e.g. MAC) was suggested to improve the Broselow tape. Underestimation of weight predominated. **Weaknesses:** Incomplete statistical analysis and data presentation. Poor interpretation of results from previous studies; flawed outcome measures used (indicators of bias only). ★★★★ Risk of bias: low

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Loo 2013 [56]	875	Singapore	P	1 to 10yrs	EPLS, Luscombe, Broselow tape	Yes	**Main Results:** The Broselow tape 2007 B was used. The Broselow tape was more accurate than formulas. EPLS underestimated, Luscombe overestimated weight, but EPLS performed better overall than Luscombe. Mean BMI of study population 15.9 kg/m^2. Good statistics. **Weaknesses:** Broselow tape not actually used. ★★★★★★★ Risk of bias: low
Suh 2013 [57]	105072	Korea	R	–	Broselow tape 2005A, 2007B, 2011A	Yes	**Main Results:** Abstract. Large retrospective database sample. The Broselow tape 2011A was more accurate than older versions. **Weaknesses:** Statistical analysis incomplete. Broselow tape not actually used. ★★★★★★ Risk of bias: low
Wells 2013 [58]	453	South Africa	P	0 to 12yrs	Broselow tape, PAWPER tape	Yes	**Main Results:** The Broselow tape 2007 B was used. Multi-centre study of habitus-modified length-based weight estimation. Population with mixed under- and overweight. The PAWPER tape performed better than Broselow tape in every category analysed and was better than any previously published system. **Weaknesses:** Assessment of body habitus based on visual assessment. ★★★★★★★★ Risk of bias: low
Young 2013 [59]	207	USA	P	1 to 9yrs	EPLS, Broselow tape, parental estimates, Luscombe, finger counting	Yes	**Main Results:** Finger counting system as accurate as Broselow tape and more accurate than other formulas. Conceptually a simple system. To increase the accuracy weight-estimation systems may cause increased complexity and stress during resuscitations. The finger counting method is equivalent to formula Wt = 2.5 × age(yrs) + 7.5. Median BMI of study population was 17.2 kg/m^2. **Weaknesses:** Limitations in statistical analysis. Broselow tape not actually used and version not reported. ★★★★★★★ Risk of bias: low
Allison 2014 [60]	2102	Australia	R	0 to 5yrs	EPLS, BG, Luscombe, Argall, Nelson, Broselow tape, Sandell tape	Yes	**Main Results:** The Broselow tape 2007 B was used. Aboriginal and Torres Strait Island children included (low weight-for-length). The Broselow tape was most accurate in this study. Only published study of Sandell tape. **Weaknesses:** Broselow tape not actually used. Limited statistics and data presentation. Narrow age range evaluated. Very fat and very thin children excluded from study. ★★★★ Risk of bias: unknown
Batmanabane 2014 [8]	374	India (Cat III)	P	0 to 16yrs	EPLS, ARC, Argall, BG, Broselow tape, Cattermole, Leffler, Luscombe, Nelson, Shann, TJ, TK, Mercy method	Yes	**Main Results:** The Mercy method performed well in Indian children, similar to that shown in Western populations. Poor performance of the Broselow tape. Good statistics. Overestimation of weight by all methods except Mercy. **Weaknesses:** Broselow tape not actually used and Broselow tape version not reported. ★★★★★★★ Risk of bias: low
Chiengkriwate 2014 [61]	3869	Thailand (Cat II)	R	0 to 15yrs	Broselow tape	Yes	**Main Results:** The Broselow tape 2007 edition A used. The Broselow tape underestimated weight in Thai children, more so in older children, similar to findings in Western populations: Broselow tape performance consistently at a PW10 of just below 60%. **Weaknesses:** Broselow tape not actually used. ★★★★★★ Risk of bias: low
Dicko 2014 [7]	473	Mali (Cat III)	P	0 to 16yrs	Mercy, EPLS, ARC, Broselow tape, Nelson	Yes	**Main Results:** Mercy method performed extremely well in this population in Mali, similar to its performance elsewhere in the world. Other methods, including the Broselow tape, overestimated weight. BMI of study population 15.6 kg/m^2, with 22% underweight and 1.7% overweight or obese. Good inter-rater reliability. **Weaknesses:** Some limitations in statistics. Broselow tape not actually used and version not reported. ★★★★★★ Risk of bias: low

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Asskaryar 2015 [62]	1185	India (Cat III)	P	1mo to 12yrs	Broselow tape	Yes	**Main Results:** The Broselow tape 2007 edition B was used. The Broselow tape significantly overestimated weight in Indian children. The authors claimed that an 8% modification of the tape improved its accuracy, although the improved performance was not substantially better than the original and was still below acceptable performance. Recalibrating bias alone is not enough when precision is low. **Weaknesses:** Limited data presentation and statistical analysis. ★★★★★ Risk of bias: low
Britnell 2015 [63]	376	New Zealand	P	5 to 10yrs	EPLS, Shann, Theron, Broselow tape	Yes	**Main Results:** The Broselow tape 2011 edition A was used. The Broselow tape was more accurate than age-based formulas in children <143 cm. Current acceptance of formulas needs to change. Large differences in accuracy of weight estimation shown in different ethnic groups. There was a large proportion of Pacific Island children in sample. Broselow tape could not be used in one fifth of children, but best ever performance of the Broselow tape in a study. Habitus was assessed but data not presented. **Weaknesses:** Limited and incomplete statistics. ★★★★★ Risk of bias: low
Chavez 2015 [64]	324	USA	P	1mo to 12yrs	Broselow tape, PAWPER, APLS, MAC	Yes	**Main Results:** Age-based formulas and the MAC formulas performed badly. The Broselow tape performed better and the PAWPER was most accurate overall, although not as accurate as in previous studies. Underestimation of obesity (and habitus score) caused underestimation of weight. High level of obesity in study population. **Weaknesses:** Broselow tape version not reported. Limited and incomplete statistics. PW5 mistaken for PW10 by authors – confusing for readers. ★★★★★ Risk of bias: low
Georgoulas 2015 [65]	300	South Africa (Cat III)	P	1mo to 12yrs	Broselow tape, PAWPER, Wozniak, Mercy method	Yes	**Main Results:** The Broselow tape 2011 edition A was used. Poor population with high proportion of underweight children. First comparative study of these methodologies. The PAWPER tape performed best, but good performances from Wozniak and Mercy methods. The Broselow tape was the worst performer. Relatively weaker performance by all methods in infants, but Wozniak especially was very weak. **Weaknesses:** Assessment of body habitus done by single researcher. ★★★★★★★★ Risk of bias: low
Khouli 2015 [66]	815	Mexico (Cat II)	P	0 to 12yrs	Broselow tape	Yes	**Main Results:** The Broselow tape was not accurate in Mexican population. Reasonable statistics. Both under- and overestimation found to be a problem. Nearly half of children had at least one colour zone error. **Weaknesses:** Broselow tape not actually used and Broselow tape version not reported. Poor interpretation of findings. ★★★★★ Risk of bias: low
O'Leary 2015 [67]	199	Australia	P	0 to 14yrs	PAWPER, APLS, Luscombe, BG, Broselow tape, Mercy method	Yes	**Main Results:** Age-based formulas performed badly. The Broselow tape and Mercy method performed significantly better and the PAWPER was most accurate overall. All systems performed worst in infants. There was a reasonably good performance of the Broselow tape, possibly because of newer edition used. **Weaknesses:** Broselow tape version not reported. ★★★★★★ Risk of bias: low
Young 2015 [68]	207	Philippines (Cat III)	P	1 to 9yrs	EPLS, APLS, Luscombe, BG, finger counting, Broselow tape	No	**Main Results:** The Broselow tape 2011 edition A was used. The Broselow tape performed best in this population, and the updated APLS formula performed worst. **Weaknesses:** Broselow tape not actually used. Very limited and incomplete statistical analysis. Does not allow for comparison to other studies or for inclusion into meta-analysis. ★★★★ Risk of bias: low

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Abdel-Rahman 2015 [69]	400**	USA	P	2mo to 16yrs	EPLS, Luscombe, DWEM, healthcare provider guesses, Broselow tape, 2DMT, 3DMT	Yes	**Main Results**: "Real world" performance of weight estimation less accurate than when performed by experts. Calculation errors were common with age-based formulas. Weight and habitus were often underestimated by visual inspection. Usage errors with Broselow tape and Mercy tapes were common. **Weaknesses:** Not all modern weight estimation systems evaluated. ★★★★★★ Risk of bias: low
Talib 2015 [70]	318	USA	P	0 to 18yrs	APLS, Broselow tape, MAC formula, Mercy method	No	**Main Results**: The Mercy method performed better than Broselow tape and age-based formulas in children with Down syndrome. No system performed well in this population. **Weaknesses:** Incomplete statistics obscure the poor performance of all methods, including the Mercy method. ★★★ Risk of bias: high
AlHarbi 2016 [71]	3537	Saudi Arabia	P	1mo to 12yrs	Broselow tape 2007 B and Broselow tape 2011A	No	**Main Results**: The Broselow tape 2011A performed better than Broselow tape 2007 B in this population. The authors suggested that the tapes were accurate. The method of statistical analysis does not support the conclusions drawn in this paper. **Weaknesses:** It was unclear if the Broselow tape was used or if Broselow tape weights were derived from length measurements. Limited, incomplete and inappropriate statistical analysis. ★★★ Risk of bias: high
Aliyu 2016 [72]	300	Nigeria (Cat II)	P	0 to 5yrs	Broselow tape, APLS	Yes	**Main Results**: The Broselow tape and APLS formulas performed well in this population. Contrary to the authors conclusions, although the Broselow tape and APLS formula performed similarly, they were both inaccurate. **Weaknesses:** Only young children included. Not clear if Broselow tape used, or if derived from length measurements. Broselow tape edition not reported. Incomplete statistical analysis. ★★★★★ Risk of bias: low
Bowen 2016 [73]	1381	Zambia (Cat II)	P	0 to 14yrs	Broselow tape, APLS, EPLS, ARC, Argall, BG, Garwood, Luscombe, Michigan, Nelson, Park, Shann, Theron, Tintinalli	Yes	**Main Results**: Broselow tape performed better than every formula in this population, BG and Michigan formulas performed worst. None of the methods were accurate and all methods overestimated weight. **Weaknesses:** Broselow tape not actually used. Broselow tape version not reported. ★★★★★★ Risk of bias: low
Clark 2016 [6]	583	Sudan (Cat III)	R	6mo to 5yrs	Broselow tape	Yes	**Main Results:** Study in South Sudan, the "hungriest place on earth" where 61% of study population was malnourished. The Broselow tape performed very poorly. There was up to two colour zone overestimation in severely malnourished children with only 26% agreement in normally nourished children: a potentially dangerous overestimation of weight in undernourished children. **Weaknesses:** Very limited statistical analysis and data presentation. Broselow tape not actually used and Broselow tape version not reported. ★★★★ Risk of bias: low
Jung 2016 [74]	906	Korea	P	0 to 17yrs	Broselow tape, novel device	Yes	**Main Results**: The novel device performed better than the Broselow tape in all outcome measures and was quicker to use. Both devices underestimated weights. Overweight and underweight children were often misclassified into wrong habitus category. Broselow tape 2011 edition A. **Weaknesses:** Device is not commercially available. Incomplete statistical analysis. ★★★★★★ Risk of bias: low
Jung 2016 [75]							Non-systematic review. **Main Results:** Weight frequently underestimated in older children. Differences in body habitus account for this error, which needs further research. **Comments**: Article in Korean. **Weaknesses:** Non-systematic review. No objective assessment of methodologies.

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Lowe 2016 [76]	3018	USA	R	0 to 13yrs	Broselow tape, Handtevy tape	Yes	**Main Results**: The Broselow tape performed better than the Handtevy tape in all outcome measures. Both tapes underestimated weights. Although the authors recognised the increased accuracy when obese children were excluded, they still erroneously advocated "recalibration" of the tapes. Broselow tape 2011 edition A. **Weaknesses:** Tapes not actually used. Incomplete statistical analysis. ★★★★★ Risk of bias: low
Mishra 2016 [77]	603	India (Cat III)	P	0 to 10yrs	Broselow tape	No	**Main Results**: Broselow tape performed best in smallest children. Broselow tape 2007 edition B. **Weaknesses:** Limited and incomplete statistical analysis. ★★★ Risk of bias: high
Nosaka 2016 [78]	237	Japan	P	0 to 10yrs	EPLS, Park, Broselow tape, parental estimates	Yes	**Main Results**: Parental estimates were most accurate, then Broselow tape then APLS formula. Mothers' weights, as well as Broselow tape and EPLS estimations were extremely accurate. The BMI for this population suggests that very few obese children were included and the sample was skewed towards very young children. Broselow tape 2007 edition B. **Weaknesses:** Limited and incomplete statistical analysis. ★★★★★ Risk of bias: low
Ralston 2016 [79]	453990	Multicentre International (Cat II)	R	6mo to 5yrs	Broselow tape, novel MAC-based formulas	Yes	**Main Results**: A model incorporating height and MAC was the most accurate. Broselow tape 2011 edition A less accurate than 2007 edition B in this population. This was a very large multinational database study. **Weaknesses:** Broselow tape not actually used. Only very young children <5years of age were included. ★★★★★ Risk of bias: low
Sahar 2016 [80]	1163	Malaysia (Cat II)	P	0 to 12yrs	Broselow tape	Yes	**Main Results**: Broselow tape underestimated weight in small children and overestimated weight in older children. It was not accurate overall. As with studies elsewhere there was a large variation in accuracy. **Weaknesses:** Broselow tape version not reported. Limited and incomplete statistical analysis. ★★★★★ Risk of bias: low
Tanner 2016 [81]	178	USA	P	2 to 18yrs	Broselow tape	No	**Main Results**: The Broselow tape was very inaccurate in overweight and obese children, who made up more than half the sample. Habitus assessment was poor by parents and nurses, but better by the principal investigator. Using a corrective formula based on waist circumference to adjust the Broselow tape weight improved accuracy in obese children. **Weaknesses:** Broselow tape version not reported. Limited, unclear and incomplete staually used. Only very young children <5years of age were included. ★★★★★ Risk of bias: low
Sahar 2016 [80]	1163	Malaysia (Cat II)	P	0 to 12yrs	Broselow tape	Yes	**Main Results**: Broselow tape underestimated weight in small children and overestimated weight in older children. It was not accurate overall. As with studies elsewhere there was a large variation in accuracy. **Weaknesses:** Broselow tape version not reported. Limited and incomplete statistical analysis. ★★★★★ Risk of bias: low
Tanner 2016 [81]	178	USA	P	2 to 18yrs	Broselow tape	No	**Main Results**: The Broselow tape was very inaccurate in overweight and obese children, who made up more than half the sample. Habitus assessment was poor by parents and nurses, but better by the principal investigator. Using a corrective formula based on waist circumference to adjust the Broselow tape weight improved accuracy in obese children. **Weaknesses:** Broselow tape version not reported. Limited, unclear and incomplete statistical analysis. Only included children who fell within the length limitations of the tape. ★★★ Risk of bias: high
Young 2016 [82]							Systematic review. **Main Results:** Parental estimates are the most accurate technique, followed by length- and habitus-based methods. Broselow tape more accurate than age formulas. **Weaknesses:** Limited evaluation of data in this review.

Table 1 (*Continued*)

(a)

Author, date	Study size (N)	Country	Design	Patient ages	Estimation techniques evaluated	Included in meta-analysis	Main results, Newcastle-Ottawa rating, Risk of Bias assessment
Waseem 2017 [12]	538	USA	R	0 to 8yrs	Broselow tape	No	**Main Results**: Broselow tape underestimated weight in older children. It was not accurate in nearly half the population. Broselow tape 2011 edition A. Many underweight and obese children included which resulted in poor performance. **Weaknesses:** Broselow tape not actually used. Limited and incomplete statistical analysis. Only included children who fell within the length limitations of the tape. ★★★ Risk of bias: high
Wells 2017 [83]	328	South Africa	P	0 to 16yrs	Broselow tape, PAWPER, Wozniak, Mercy method	Yes	**Main Results:** This was a population selected for older children and for children with deviations from "average" weight-for-length. The Broselow tape performed poorly in this study, the Wozniak method and the Mercy method showed intermediate accuracy and the PAWPER was most accurate overall. The extended PAWPER tape worked well in this population. **Weaknesses:** The Mercy method was used in a simulated resuscitation setting (supine children), which may have affected its accuracy. ★★★★★★★ Risk of bias: low
Wells 2017 [84]	1085	South Africa	P	0 to 16yrs	Broselow tape	No	**Main Results:** Habitus-modified models greatly improved the accuracy of the Broselow tape. **Weaknesses:** The visual assessment of habitus was performed by moderately experienced users. ★★★★★★★ Risk of bias: high
Whitfield 2017 [85]							As for Wozniak 2012.

(b)

Author, date	Size (N)	Design	Endpoints	Risk of Bias	Major findings; comments; major limitations
Luten 1992 (USA) [86]	213	Prospective derivation and validation of length-based ETT size estimation	Endotracheal tube size	Low	**Main Results:** The Broselow tape predicted correct uncuffed endotracheal tube size in 77% of children and 99% within 0.5 mm of correct size. **Comments**: One of the only studies to objectively evaluate the accuracy of equipment size prediction by the Broselow tape. Other equipment sizes determined by modified Delphi method. **Weaknesses:** The relevance of uncuffed endotracheal tube sizes is far less now than 25 years ago. ★★★★★★★
Lanoix 1999 (USA) [87]	N/A	Clinical communication		–	**Main Results:** Colour-coding organisation of resuscitation equipment facilitates emergent medical management. **Comments**: Theoretical concept proposition. **Weaknesses:** No evidence presented.
Hohenhaus 2001 [88]	N/A	Clinical report		–	**Main Results:** Broselow tape recommended for use, but many errors when used by healthcare providers with insufficient training. **Comments**: Broselow tape helpful only when used correctly. **Weaknesses:** No quantitative data presented.
Vilke 2001 [89]	20	Prospective simulation study evaluating accuracy of adrenaline dose by paramedics	Adrenaline dose	High	**Main Results:** The authors claim that 95% of estimates were within acceptable error range, but there was an unrealistic target range, with no supporting evidence basis. Tenfold errors in drug doses occurred in 10% of cases. The Broselow tape was more accurate than guesses. **Weaknesses:** Very poor statistics. Limited data analysis made findings unreliable and uninterpretable. ★★★★
Luten 2002 (USA) [90]	N/A	Clinical communication/editorial			**Main Results:** Drug dose calculations must be eliminated and a global strategy to limit extraneous thinking during emergency management is required. **Comments**: A review of cognitive stressors experienced during paediatric resuscitation. **Weaknesses:** No data presented.
Slishman 2002 (USA) [91]	7	Prospective simulation study comparing standard Broselow tape techniques and a new device, the "per-kilo doser"	Time to drug withdrawal	Unknown	**Main Results:** Drug administration faster with new "per-kilo doser" device, by about 30 s per drug. **Comments**: 7 nurses each preparing 4 medications using standard Broselow tape techniques and 4 using a new device, the "per-kilo doser" Broselow tape colour zones were used for both systems. **Weaknesses:** Small study. No standardised control group. ★★★★★★
Hohenhaus 2003 (USA) [92]	N/A	Abstract		–	**Main Results:** The Broselow tape requires training for proper use. **Comments**: Reiteration of the fact that the Broselow tape is not as easy to use as might be expected. **Weaknesses:** No data presented.

Table 1 (*Continued*)

(b)

Author, date	Size (N)	Design	Endpoints	Risk of Bias	Major findings; comments; major limitations
Shah 2003 (USA) [93]	28	Prospective simulation crossover study with 28 doctors comparing traditional dosing system and colour-coded system.	Deviation from recommended dose range and deviation from recommended equipment sizes	Low	**Main Results:** Colour-coding significantly reduced the number of errors. Participants preferred the Broselow tape system to the standard system. **Comments**: Supplementary information is essential to the success of the Broselow tape. **Weaknesses:** Colour-coded drug sheets used in addition to the Broselow tape. ★★★★★★★
deBoer 2004 (USA) [94]	N/A	Clinical communication.			**Main Results:** Colour-coding can be used for other applications e.g. spinal immobilisation appropriate for size. **Comments**: An integrated approach to all aspects of the management of the critically ill or injured child is essential. **Weaknesses:** No data presented.
Hohenhaus 2004 (USA) [9]	N/A	Clinical communication.		–	**Main Results:** The Broselow tape may cause significant weight estimation errors if used incorrectly. The Broselow tape is intended more for equipment size determination than weight estimation. **Comments**: Some errors and weaknesses of the 1998 edition highlighted. **Weaknesses:** Limited quantitative data presented.
Moore 2004 (USA) [95]	144	Prospective simulation study assessing the accuracy of Broselow tape use by paramedics	Dose of resuscitation drugs	Unknown	**Main Results:** Despite using Broselow tape, only 56% correct medication doses delivered. Despite improving weight estimation, the Broselow tape did not decrease medication errors. **Weaknesses:** Limited data analysis. ★★
Agarwal 2005 (USA) [96]	21	Prospective crossover simulation trial with 21 paediatric-trained healthcare providers comparing standard resuscitation cart with colour-coded Broselow cart.	Time to and accuracy of selection of appropriate medical equipment along with participant satisfaction	Low	**Main Results:** The Broselow cart was preferred by two thirds of participants. It was slightly faster and slightly more accurate than a standard cart. **Comments**: Although the accuracy of the Broselow cart was reported to be more accurate, review of the actual data shows small and inconsistent effect size. **Weaknesses:** Small sample. Only equipment was evaluated. The importance of the sizes of much of the equipment evaluated is debatable. ★★★★★★★
deBoer 2005 (USA) [1]	N/A	Clinical communication.			**Main Results:** A patient can be "bumped up" a zone if they are obese, except for medications that should be dosed according to lean or ideal body weight. Colour-coded reference materials should be used for drug dose guidelines. **Comments**: Repetition of previous articles with no evidence-based material. **Weaknesses:** No data presented to support content. Over-reliance on reference to opinion-based publications of the developers.
deBoer 2005 (USA) [97]	N/A	Clinical communication.			**Main Results:** "In most cases of emergency resuscitation or stabilisation, the medications administered to children are the same as those for adults. The dosages, however, are dramatically different" "The simplest [solution] is a book, in print or in an electronic format [. . .] with colour-coded pages. All doses are pre-calculated not only in milligrams (mg), but also in terms of the millilitres (ml) of a standard concentration". **Comments**: The Broselow tape should not be used as a stand-alone resuscitation aid. **Weaknesses:** No original data presented.
Hohenhaus 2005 (USA) [98]	N/A	Editorial/clinical communication.		–	**Main Results:** Broselow tape colour zone is a "vital sign". Delay at any point in emergency care should be considered an error. Administrators should ensure that clinicians have the tools they require to deliver paediatric-specific care. **Comments**: Further emphasis of the necessity avoid calculations and to have the right equipment available. **Weaknesses:** Opinion piece.
Frush 2006 (USA) [99]	89	Randomised control trial of Broselow tape use with and without training in its use.	Dosing deviation from accepted dose range and time to determine the dose for each medication prescribed	Low	**Main Results:** Slight increase in speed of dose prescription, with increased accuracy. New clinical tools (such as Broselow tape) may lead to new or additional errors. **Comments**: Broselow tape only used correctly in 3–5% of untrained individuals! Doses evaluated in milligram format. **Weaknesses:** No evaluation of administration-ready time i.e. time to calculate dilutions and volume to administer. ★★★★★★★
Kaji 2006 (USA) [100]	141	Observational study of Emergency Medical Services personnel's errors before and after introduction of Broselow tape into protocol	Accuracy of dose of adrenaline during cardiac arrest	High	**Main Results:** Broselow tape increased the likelihood of correct and semi-accurate dose calculation with a small to medium effect size. **Comments**: Drug dose delivery still only correct in 50% of cases with Broselow tape **Weaknesses:** Small numbers. ★★★★

Table 1 (*Continued*)

(b)

Author, date	Size (N)	Design	Endpoints	Risk of Bias	Major findings; comments; major limitations
Frush 2007 (USA) [101]	N/A	Policy statement.		–	**Main Results:** Broselow tape should be used, but "some studies have described a potential increase in medical errors when using the Broselow tape because of its design and the fact that it is often used incorrectly". **Comments**: The Broselow tape should not be used without training and without being part of a comprehensive resuscitation aid system. **Weaknesses:** No data presented.
Luten 2007 (USA) [102]	N/A	Editorial comment.			**Main Results:** No substantiation for setting acceptable accuracy of weight estimation at 10%. Broselow tape estimates ideal body weight, therefore obesity not relevant and overdose unlikely in emaciated children. **Comments**: Many comments not substantiated by evidence. **Weaknesses:** Opinion piece.
Fineberg 2008 (Australia) [103]	16	Prospective, randomised crossover trial, comparing Broselow tape with a standardised volume-weight method.	Time to medication delivery and accuracy of drug doses.	Low	**Main Results:** New method faster and with fewer errors than Broselow tape. The calculation of volumes to administer was error-prone. **Comments**: 16 participants in 3 simulations with 13 dose determinations in each arm. Volume dose calculations had to be performed. **Weaknesses:** This volume-weight method is not commercially available. ★★★★★★★
Luten 2008 (USA) [104]	N/A	Commentary in response to Fineberg 2008.			**Main Results:** Ideal body weight might be better than total body weight as a goal; "the Broselow tape is a tool that was not designed to be used without clinical judgment". **Comments**: No evidence offered to support opinion; no goal target suggested. In this letter Luten wrote, "To address these concepts, the new addition of the Broselow Tape includes the calculated volume of medication from a preferred concentration list. This requires reducing the number of medications on the tape in order to allow adequate sized font." This has not yet materialised. **Weaknesses:** This provided an important theoretical discussion, but without providing evidence.
Wells 2008 (South Africa) [105]	N/A	Letter.		–	**Comments**: The Broselow tape has not been shown to accurately predict ideal body weight. Total body weight should be used for dose calculation in emergencies. **Weaknesses:** This provided a counter view to Luten 2008, but without providing evidence.
Feleke 2009 (USA) [106]	16	Prospective sequential simulation study in which a colour-coded medication system was compared with traditional dosing references.	Time of conversion of medication orders from dose to volume and access to preparation and administration information.	Low	**Main Results:** A colour-coded system together with the Broselow tape resulted in faster time to drug administration and fewer errors in dose and administration. The Broselow tape does not provide a pre-calculated conversion from milligrams to millilitres for most medications, which may lead to errors. **Comments**: 320 medication orders were given to 16 nurses. **Weaknesses:** Colour-coded system required for benefits of Broselow tape to be realised. ★★★★★★★★
Pinchevsky 2010 (USA) [107]	4	Retrospective comparison of three dosing strategies in obese children during cardiac arrest.	Drug dose deviations	High	**Main Results:** All dosing strategies were very different and all had large errors. **Comments**: It is unclear whether this study adds anything to the field other than that there needs to be consensus on how drugs are dosed in obese children. **Weaknesses:** No clarity on how ideal body weight was determined and which dose was used as the reference dose value. Very small sample size. ★★★★

Table 1 (*Continued*)

(b)

Author, date	Size (N)	Design	Endpoints	Risk of Bias	Major findings; comments; major limitations
Kelly 2012 (Australia) [108]	N/A	Book chapter.		–	**Main Results:** Best systems to be used, in order of accuracy: parental estimates, Broselow tape, age-based formulas. **Comments**: Discussion primarily on the weight-estimation function of the Broselow tape. **Weaknesses:** No mention of acceptable targets for weight estimation or weaknesses of age formulas. Subjective assessment of studies only.
Lammers 2012 (USA) [109]	45	Prospective simulation study to detect errors in management.	Unique performance scoring protocol to determine errors during resuscitation.	Low	**Main Results:** Use of the Broselow tape alone did not eliminate errors. The Broselow tape was used incorrectly often enough to be of concern. **Comments**: A 10% error was regarded as the maximum allowable. **Weaknesses:** Limited quantitative data reported. ⋆⋆⋆⋆⋆
Meguerdichian 2012 (USA) [110]	N/A	Non-systematic review.		–	**Main Results:** The Broselow tape is the most consistent and reliable tool for weight estimation, but habitus-based weight adjustment for Broselow tape is logical. Parental estimates may rival the Broselow tape, but parents may be absent or uncertain, especially under stress. Underdosing might be prudent in emergencies. **Comments**: The author acknowledges that the degree of acceptable error is difficult to define. **Weaknesses:** No evidence provided of efficacy of Broselow tape in reducing medication errors. No suggestion of goal target accuracy required. Some controversial opinions about drug dosing.
Abdel-Rahman 2014 (USA) [111]	N/A	Non-systematic review.		–	**Main Results:** Some experts have suggested that weight estimation cannot be accurate. This is likely to be to the disadvantage of children as dual length-and habitus-based can achieve acceptable accuracy. **Comments**: Brief review of weight estimation systems. **Weaknesses:** No target of weight estimation accuracy suggested; Mercy method recommended for environments where no scale available – but no mention of emergency use.
Lammers 2014 (USA) [112]	142	Prospective simulation study to detect errors in management.	Performance scoring protocol used to determine errors during resuscitation.	Low	**Main Results:** Incorrect doses were found for drugs not on Broselow tape. Large errors still possible with drugs on tape. **Comments**: Simulation study with 142 participants in 62 sessions. **Weaknesses:** Limited details on quantitative data presented. ⋆⋆⋆⋆⋆
Moreira 2015 (USA) [10]	10	Prospective crossover simulation study comparing colour-coded syringes and conventional drug administration.	Time from initiation of medication preparation to completed administration and dose errors and critical errors.	Low	**Main Results:** Colour-coded prefilled syringes improved time to delivery of medication with a reduction in critical errors: 17% with conventional and 0% with colour-coded technique. **Comments**: of 10 doctor-and-nurse teams comparing colour-coded syringes and conventional drug administration. Within 10% were still considered an error; outside this range was a critical error. **Weaknesses:** Colour coded, prefilled syringes are not commercially available. ⋆⋆⋆⋆⋆⋆⋆
Stevens 2015 (USA) [113]	10	Prospective crossover simulation study comparing colour-coded syringes and conventional drug administration.	Time from initiation of medication preparation to completed administration and dose errors and critical errors.	Low	**Main Results:** Colour-coded prefilled syringes slightly decreased time to delivery of medication with a reduction in critical errors: 39% with conventional and 0% with colour-coded technique. **Comments**: Crossover simulation study of 10 paramedics comparing colour-coded syringes and conventional drug administration. **Weaknesses:** Colour coded, prefilled syringes are not commercially available. ⋆⋆⋆⋆⋆⋆⋆
Rappaport 2016 [114]	80	Prospective simulation study to detect errors in drug doses from Broselow tape and Handtevy system.	Drug dose errors >20%; incorrect concentration of drugs; time to administer	Low	**Main Results:** High error rates for both tapes, but especially Broselow tape (from 21% to 64% with different drugs). Tapes frequently used incorrectly. Handtevy tape allowed for faster administration of drugs. **Comments**: More information available on Handtevy tape which reduced errors. **Weaknesses:** Correct weight was defined as weight on the tapes, rather than actual weight. ⋆⋆⋆⋆⋆⋆

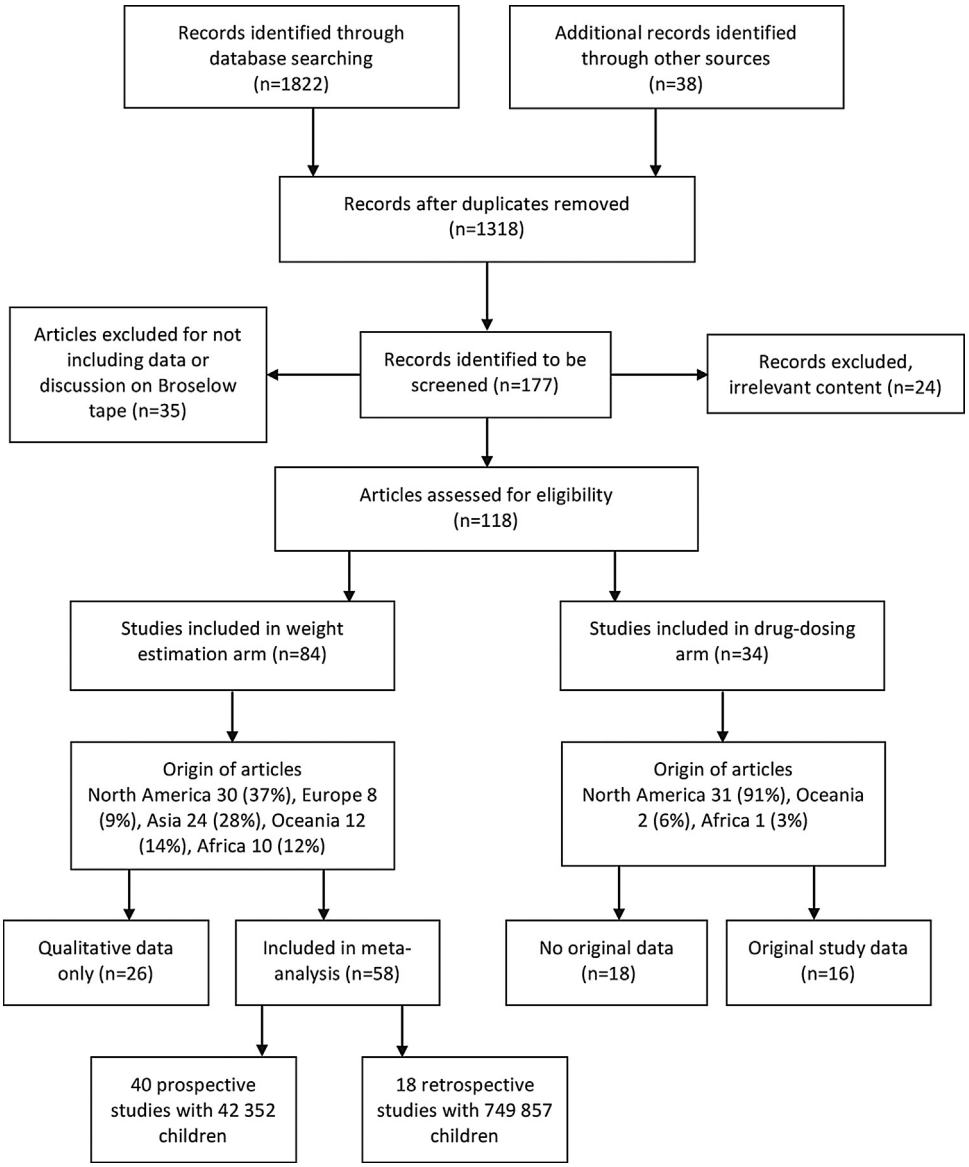

Fig. 1. Flow diagram for article identification and selection. In the "origin of articles" box, Oceania refers to Australia and New Zealand.

2.8 Software

Data were analysed and graphics generated using Microsoft excel for Mac (Microsoft. Microsoft Excel for Mac. Redmond, Washington: Microsoft, 2016), RevMan (Review Manager (RevMan) [Computer program]. Version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014) and Prism 6 (GraphPad Prism version 6.00 for Mac, GraphPad Software, San Diego California USA, www.graphpad.com).

3 Results

3.1 Changes in the Broselow tape from 1989 to 2011

The tape has changed substantially in appearance and content over the years. The content, format and changes in the tapes from edition-to-edition are shown and described in the supplementary material (Supplementary Fig. 1 and Supplementary Table 3).

3.2 Systematic review – study selection

The details of the evaluated and included studies are shown in Fig. 1.

3.3 Meta-analysis – individual study and pooled-data findings

The bias and precision data for each study and for the pooled data analysis are shown in Fig. 2. The data on the accuracy of the Broselow tape in each included study and for the pooled data are shown in Fig. 3. The data on the performance of the tape in populations with different prevalence of underweight children are included in these figures. There was no detectable change in the performance of the Broselow tape over time or from edition to edition. The results of direct pair-wise comparisons between the Broselow tape and various other weight-estimation methods can be found in Fig. 4.

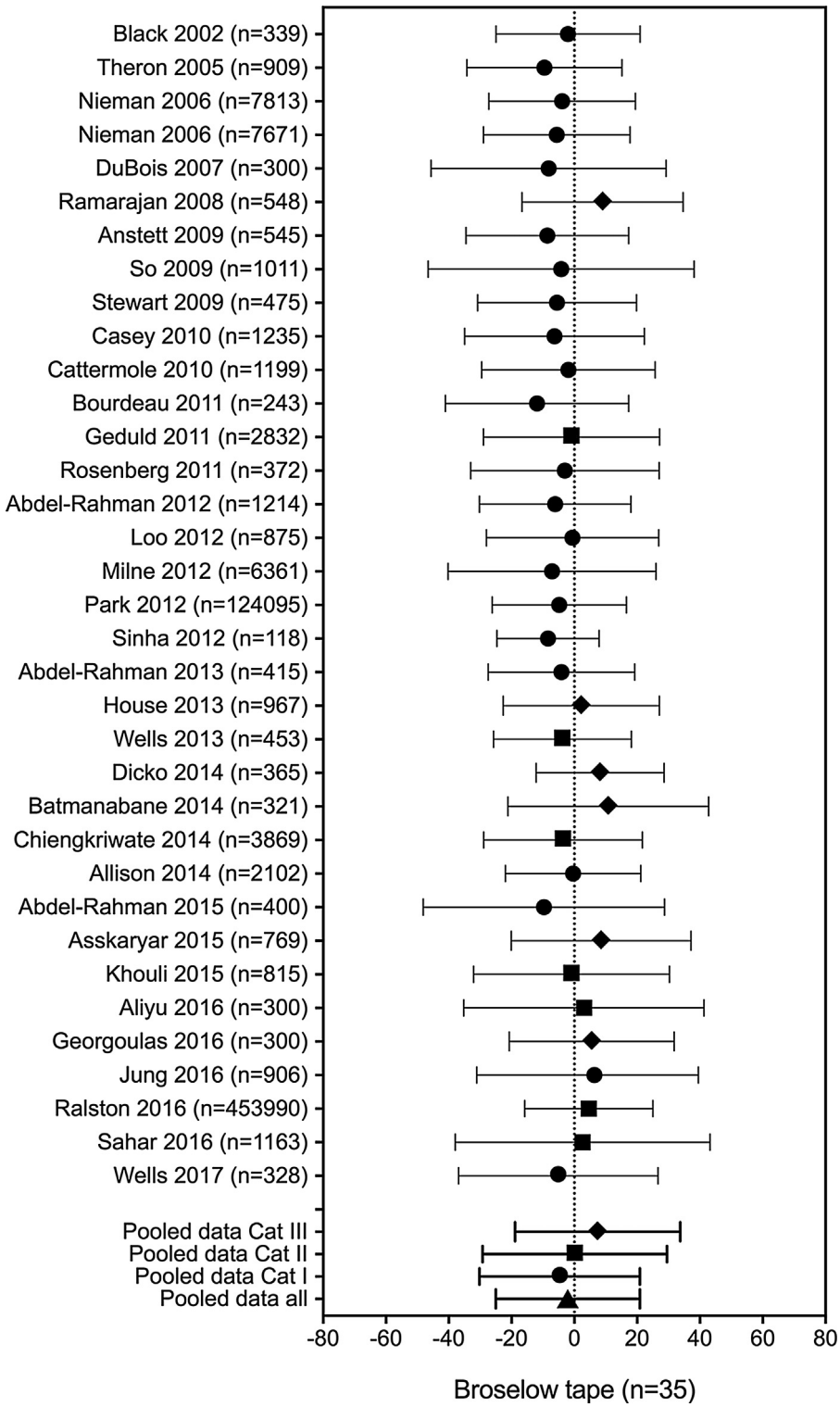

Fig. 2. Forest plot of the included studies and pooled data showing bias and 95% limits of agreement. Studies from countries with a low prevalence of underweight (Category I) are indicated by circles, studies from countries with a medium prevalence of underweight (Category II) are indicated by diamonds and studies from countries with a high prevalence of underweight (Category III) by squares.

When evaluating the performance data of the Broselow tape from individual studies, the following findings were consistently reported:

- The Broselow tape consistently was significantly *more accurate* than healthcare provider guesses (two studies) and age-based formulas (25 studies).
- Some studies showed the Broselow tape to be more accurate than parental guesses (two studies) and some showed it to be less accurate (five studies). The differences were small.
- There were mixed results when comparing the Broselow tape with the earliest dual length- and habitus-based system, the Devised Weight Estimating Method (one study favoured Broselow tape, one study favoured the Devised Weight Estimat-

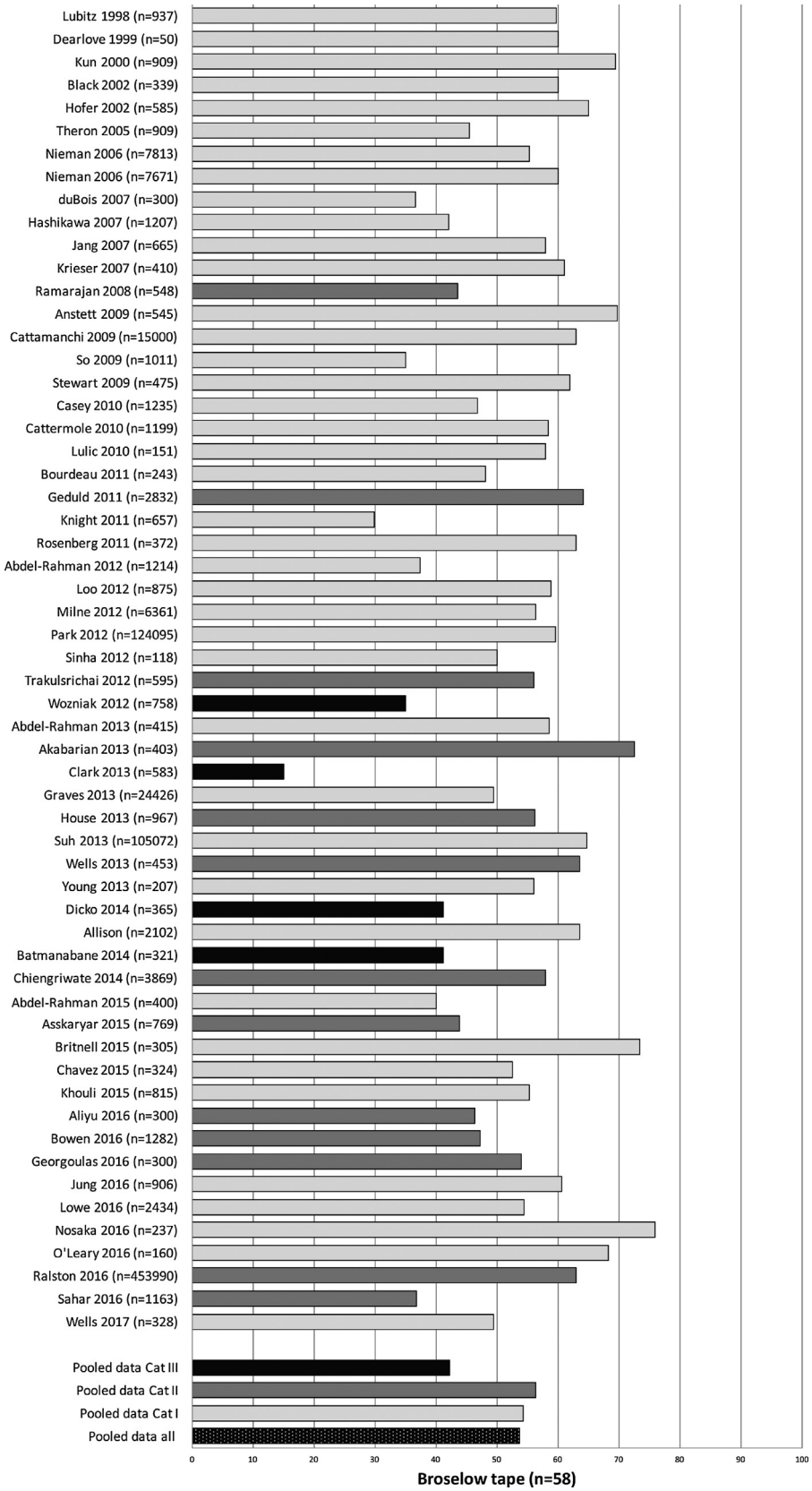

Fig. 3. Bar chart showing the accuracy data from the included studies and pooled data – percentages of weight estimations accurate to within 10% of actual weight are shown (PW10). Studies from countries with a low prevalence of underweight (Category I) are indicated by pale grey bars, studies from countries with a medium prevalence of underweight (Category II) are indicated by dark grey bars and studies from countries with a high prevalence of underweight (Category III) by black bars. There was a significant difference between the pooled accuracy of Category I and Category II studies when compared with Category III studies (Fisher exact test, $p < 0.0001$).

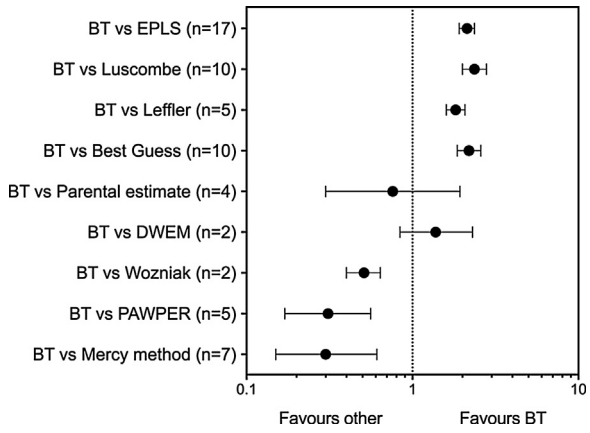

Fig. 4. Forest plot of direct comparisons between the Broselow tape and other weight estimation systems. These comparisons were made using accuracy data (percentages of weight estimations accurate to within 10% of actual weight) and inverse-variance random effects modelling. The Broselow tape was significantly *more accurate* than the four age-based formulas (for which paired data was available) with a small effect size. There was no difference in accuracy between the Broselow tape and parental estimates and the Devised Weight Estimating Method (DWEM). The Broselow tape was significantly *less accurate* than the three newer dual length-and habitus-based systems for which there was paired data.

ing Method and one reported no difference). The differences were small.

- The Broselow tape consistently performed *less accurately* than every modern dual length- and habitus-based system – the Mercy method, the PAWPER tape and the Wozniak method (14 studies). The differences had a large effect size. A description of the dual length- and habitus-based systems is contained in Supplementary Table 4.

3.4 Subgroup analysis findings

About half of the included studies (50% for bias and precision data and 42% for accuracy data) contained usable subgroup data, based on weight groupings, which can be found in Table 2. The Broselow tape was most accurate in children between 10 and 25 kg, slightly less accurate in children <10 kg and least accurate in children >25 kg.

The following main findings can be summarised from the studies that could not be incorporated into the pooled data analysis:

- In studies where children <145 cm were not excluded, the Broselow tape was frequently too short to provide a weight estimate in as many as 40% of children (seven studies) [5,41,44,47,50,53,83].
- When the Broselow tape was compared with healthcare provider guesses, the Broselow tape always performed better (two studies) [3,30].
- When the Broselow tape was compared with parental estimates, parental estimates were always more accurate (three studies) [27,28,30]; if the data from the studies included in the meta-analysis were included, parental estimates were found to be better in eight of the ten studies.
- When the Broselow tape was compared with age-based formulas, the Broselow tape was always more accurate (seven studies) [19–21,27,28,68,70].
- Three studies considered the Broselow tape to be acceptably accurate only in younger children <120 cm and <20 kg [24,33,53].
- One study showed a length-based formula modified for body habitus to be more accurate for drug dosing than the Broselow tape [36].

3.5 Drug dosing guideline findings

Of the 16 studies with original data, seven studies used time to medication delivery or medication-delivery readiness as a primary outcome:

- One study evaluated the Broselow tape before and after training and showed that training significantly improved the accuracy and speed of use of the Broselow tape [99].
- Two studies compared the Broselow tape plus colour-coded drug dosing reference material against traditional dosing references and found the Broselow system to be superior [93,106].
- Four studies compared other drug delivery aids or techniques with the Broselow tape and all four showed faster times and fewer errors than with the Broselow tape [10,91,103,113].

Twelve studies appraised the accuracy of drug dosing using the Broselow system:

- The Broselow tape was more accurate than guessing doses (one study) [89].
- The Broselow tape plus colour-coded dosing assets (e.g. drug calculation sheets) were more accurate than traditional dosing references (three studies).
- The use of the Broselow tape alone (without colour-coded dosing assets) did not eliminate errors (six studies) [10,89,95,103,112,113].
- The Handtevy tape was more accurate, with fewer errors than the Broselow tape (one study) [114].

In the 18 studies with no original data, the important, repetitive themes identified were:

- Many errors are incurred when the Broselow tape is used by untrained healthcare providers and the incorrect use of the Broselow tape may lead to errors.
- Arithmetic calculations must be avoided at every stage of the drug dose computation-preparation-administration process. The Broselow tape should not be used as a stand-alone device without using colour-coded drug assets to eliminate the need for calculations.
- The Broselow system should make use of a habitus-modified weight-estimation and drug-dosing system to improve accuracy.

4 Discussion

4.1 The impact of the changes in the Broselow tape on its function

The available evidence was not convincing that the Broselow tape's weight estimation accuracy has improved significantly over the years. This has led some authors to question whether the tape is still valid, as there is evidence that both its weight estimation and drug dosing roles are suboptimal and have not successfully been adapted to a changing population [4,5]. The most concerning discovery, however, is that the most recent edition of the tape is significantly less accurate than previous editions in low- and middle-income countries, with increased overestimation of weight, which could lead to significant medication overdosing errors [79].

4.2 The Broselow tape as a weight estimation device

The bias and precision data showed a consistently high within-population variance, which was similar to the between-population variance. This suggests that, even in the same study population, the Broselow tape was unable to estimate weight consistently in chil-

Table 2
Summary of the pooled data including subgroup analyses for the accuracy, bias and precision of the Broselow tape.

	Subgroup		MPE Mean (95%CI)	LLOA (95%CI)	ULOA (95%CI)	Number of children (number of studies)	PW10 (95%CI)	Number of children (number of studies)
All	All	FE	2.1 (2.1, 2.2)	-20.6 (-20.7, −20.6)	24.9 (24.8, 24.9)	625618 (35)	61.5 (61.4, 61.6)	619100 (58)
		RE	-2.1 (-2.1, −2.0)	−25.0 (-25.1, −25.0)	20.9 (20.8, 21.0)		53.7 (53.6, 53.8)	
	<10 kg	FE	−4.4 (-4.5, −4.2)	−29.3 (-29.6, −29.0)	20.5 (20.3, 20.8)	26327 (13)	55.4 (54.8, 56.0)	27345 (19)
		RE	−1.7 (-1.9, −1.5)	−28.8 (-29.1, −28.5)	25.4 (25.1, 25.7)		54.9 (54.4, 55.5)	
	10–25 kg	FE	−3.8 (-3.9, −3.7)	−22.8 (-22.9, −22.6)	15.1 (14.9, 15.2)	51915 (15)	66.5 (66.1, 66.9)	58182 (21)
		RE	−1.6 (-1.7, −1.5)	−24.0 (-24.1, −23.8)	20.7 (20.5, 20.9)		61.7 (61.3, 62.1)	
	>25 kg	FE	−5.3 (-5.4, −5.3)	−29.4 (-29.6, −29.2)	18.7 (18.6, 18.9)	72803 (14)	53.6 (53.3, 54.0)	92969 (20)
		RE	−3.8 (-3.9, −3.7)	−34.7 (-35.0, −27.3)	27.1 (26.9, 27.3)		49.3 (49.0, 49.6)	
Category I (High income, low prevalence of underweight)	All	FE	−4.8 (-4.9, −4.7)	−27.8 (-27.9, −27.7)	18.2 (18.1, 18.3)	158926 (24)	60.1 (59.9, 60.2)	296662 (40)
		RE	−4.6 (-4.7, −4.5)	−30.2 (-30.3, −30.0)	20.9 (20.8, 21.1)		54.3 (54.1, 54.5)	
	<10 kg	FE	−4.5 (-4.7, −4.2)	−29.2 (-29.5, −28.9)	20.2 (19.9, 20.4)	25723 (9)	55.4 (54.8, 56.0)	26630 (14)
		RE	−3.3 (-3.5, −3.2)	−30.2 (-30.5, −29.9)	23.5 (23.2, 23.8)		54.2 (53.6, 54.8)	
	10–25 kg	FE	−4.0 (-4.1, −3.9)	−22.4 (-22.5, −22.2)	14.4 (14.2, 14.6)	49344 (10)	66.6 (66.2, 67.0)	55239 (15)
		RE	−3.4 (-3.5, −3.3)	−25.5 (-25.7, −25.3)	18.6 (18.5, 18.8)		62.9 (62.5, 63.3)	
	>25 kg	FE	−5.5 (-5.6, −5.4)	−29.3 (-29.5, −29.2)	18.3 (18.1, 18.4)	71030 (9)	53.5 (53.2, 53.9)	91092 (14)
		RE	−7.3 (-7.4, −7.1)	−39.6 (-39.9, −39.4)	25.1 (24.9, 25.3)		48.8 (48.5, 49.1)	
Category II (Middle income, medium prevalence of underweight)	All	FE	4.5 (4.4, 4.5)	−16.1 (-16.2, −16.1)	25.1 (25.0, 25.1)	462627 (7)	62.7 (62.6, 62.9)	465702 (10)
		RE	0.2 (0.1, 0.2)	−29.2 (-29.3, −29.1)	29.5 (29.4, 29.6)		56.3 (56.2, 56.4)	
	<10 kg	FE	−0.5 (-2.4, 1.4)	−35.9 (-39.4, −32.3)	34.9 (31.4, 38.4)	356 (2)	54.6 (50.1, 59.1)	467 (3)
		RE	−1.0 (-2.6, 0.7)	−31.6 (-34.7, −28.6)	29.7 (26.7, 32.8)		57.5 (53.0, 62.0)	
	10–25 kg	FE	−2.5 (-3.0, −1.9)	−28.5 (-29.5, −27.5)	23.5 (22.5, 24.6)	2246 (3)	63.2 (61.4, 65.1)	2618 (4)
		RE	−2.7 (-3.2, −2.2)	−26.3 (-27.2, −25.3)	20.9 (20.0, 21.9)		63.3 (61.4, 65.1)	
	>25 kg	FE	0.6 (−0.1, 1.4)	−29.5 (-29.7, −26.9)	29.5 (28.1, 30.9)	1498 (3)	61.3 (58.9, 63.7)	1602 (4)
		RE	−1.5 (-2.2, −0.8)	−29.2 (-30.5, −27.8)	26.2 (24.9, 27.6)		54.7 (52.3, 57.1)	
Category III (Low income, high prevalence of underweight)	All	FE	6.6 (6.2, 7.1)	−20.4 (-21.3, −19.6)	33.7 (32.8, 34.6)	3270 (6)	57.7 (57.1, 58.4)	19611 (9)
		RE	7.4 (6.9, 7.8)	−18.9 (-19.8, −18.1)	33.7 (32.8, 34.5)		42.2 (41.5, 42.9)	
	<10 kg	FE	3.8 (2.3, 5.4)	−21.2 (-24.2, −18.2)	28.9 (25.9, 31.8)	248 (2)	54.8 (48.6, 61.0)	248 (2)
		RE	4.9 (3.3, 6.4)	−19.7 (-22.7, −16.8)	29.4 (26.5, 32.4)		56.3 (50.1, 62.5)	
	10–25 kg	FE	9.3 (8.1, 10.6)	−12.8 (-15.1, −10.5)	31.5 (29.2, 33.8)	325 (2)	48.0 (42.6, 53.4)	325 (2)
		RE	8.8 (7.6, 10.0)	−12.9 (-15.1, −10.6)	30.5 (28.2, 32.7)		48.9 (43.5, 54.3)	
	>25 kg	FE	9.4 (7.6, 11.3)	−20.5 (-23.9, −17.1)	39.4 (36.0, 42.8)	275 (2)	39.6 (33.8, 45.4)	275 (2)
		RE	8.1 (6.3, 9.9)	−21.1 (-24.4, −17.8)	37.3 (34.0, 40.6)		42.0 (36.2, 47.8)	

dren of the same length. If habitus is not taken into account in the weight estimation, as has been recommended by previous authors, this is inevitable [2,5,16,17,32,44,55,58,73,81]. The pooled data showed an overall bias to underestimate weight, but with estimates as much as 30% below actual weight to 20% above actual weight. The differences between the populations with a different prevalence of underweight children were predictable: the Broselow tape underestimated the weight of fatter populations, and overestimated the weight of thinner populations. The weight estimation performance of the tape was not satisfactory in any population group.

The accuracy data showed a wide variation between studies, but virtually all studies failed to achieve satisfactory accuracy. Interestingly, the pooled results from populations with a medium prevalence of underweight children had the best accuracy results, most likely because of the lower prevalence of both obese and underweight children in these populations. Previous studies have shown the Broselow tape to be very accurate when limited to children of "normal" habitus, but the within- and between-population variability of body habitus precludes a consistently accurate performance, especially if the extremes of underweight or obesity are prevalent [58,81]. The poorest accuracy of the Broselow tape was in populations with many underweight children, potentially the sickest and most vulnerable to medication errors and as a result there is a very real possibility that the Broselow tape may produce a dangerously high weight overestimation in children with the highest risk of harm. This is especially true of the 2011 edition A tape: this tape is more inaccurate than older versions of the tape in low- and middle income countries because its shifted weight-zones based on high-income country growth data [79]. While additional drug doses may be administered or titrated to effect in overweight children, it is difficult to "take back" part of a dose given to an underweight child [115].

The meta-analysis pair-wise comparisons between the Broselow tape and other weight estimation systems provided some critical insights. The Broselow tape was significantly superior to age-based formulas and it is indisputably clear that age-based weight estimation should no longer be used [44,63,65,116–119]. Parental estimates of weight and Broselow estimates were not significantly different, but, given a choice between the two, parental estimates should probably be used [82]. Most notably, the Broselow tape was significantly inferior to the Mercy method, the Wozniak method and the PAWPER tape (the modern dual length- and habitus-based systems). This is further convincing evidence that safe, consistent and reproducible weight estimation cannot be performed using length alone, but length plus a measure of habitus can be extremely accurate [119,120]. The meta-analysis confirmed that there are weight estimation systems that are substantially more accurate than the Broselow tape, which should probably be considered in preference to the Broselow tape.

The advanced life support guidelines produced by both the American Heart Association and the Advance Life Support Group in the United Kingdom recommend the use of length-based weight estimation and advocate the use of length-based tapes [11,121]. These guidelines potentially need to be reconsidered in favour of dual length- and habitus-based weight estimation.

4.3 Children "too tall for the tape"

One of the other problems with the Broselow tape identified by researchers is those children "too tall for the tape" [53]. Many studies have reported a substantial proportion of children (ranging from 7% to 40%) for whom the Broselow tape could not generate an estimated weight [5,18,41,44,47,50,53,83]. According to the Broselow tape instructions, these children should be treated as adults with respect to drug doses, but this is potentially dangerous, especially as these children could be a young as 9 or 10 years of age [53]. There is no validated mechanism to procure an estimated weight using the Broselow tape for these weight estimation "orphans".

4.4 Potential habitus-based modification of Broselow tape weight estimation

While a system that has a large bias but high precision can be recalibrated, a system with low precision cannot be modified without introducing an additional variable to increase the precision. Several studies have explored the possibility of recalibrating the Broselow tape in different populations, with no success [29,62,122,123]. While this changed the bias of the Broselow tape, the overall accuracy was not improved. Only two recent studies which used a habitus-based modification of Broselow tape weight showed a meaningful improvement in accuracy, corroborating that habitus is the most important variable that affects weight-for-length [81,84]. The manufacturer's advocated method of modifying the weight estimation produced by the Broselow tape in obese children by shifting up a colour zone, has not yet been formally evaluated [102]. This system is also limited as it would not protect underweight children from overestimation of weight.

4.5 The Broselow tape and ideal body weight

The developers of the Broselow tape have defended its susceptibility to underestimate weight in populations with a high prevalence of obesity by suggesting that it actually predicts ideal body weight and not total body weight. They suggest that drug doses will therefore still be accurate in overweight and obese patients and that potential overdosing can be avoided, while underweight children should be tolerant to overdosing [102,124]. These claims are controversial and not yet established. Total body weight should still be targeted for drug dose calculations for children within the 95% BMI-for-age centile, until further definitive evidence emerges [11,105]. The optimum dosing for obese children (≥95% BMI-for-age centile) has yet to be established.

4.6 The Broselow tape and drug dose guidance

There were three main findings with respect to the Broselow tape's functioning as a drug dosing instrument. Firstly, when the tape was used as a stand-alone drug dosing guide, it was faster than standard drug reference systems (e.g. a textbook with drug doses) and produced fewer medication errors. But the occurrence of dosing errors was extremely high with the tape, producing dosing errors of more than 20% in up to 50% of dose calculations [10,89,95,100,107,113]. When drug dose determinations using the tape were compared with alternative drug-dosing systems that required no calculations to determine the appropriate drug volume to administer, the Broselow tape was inferior in both speed and accuracy to these systems [10,91,103,113]. Similarly, another tape method, the Handtevy system, because of its designated companion drug-dosing guide, produced fewer medication errors than the Broselow tape when used alone, although it estimated weight even less accurately than the Broselow tape [76,114]. The second major finding was that if the Broselow tape was used in conjunction with a supplementary colour-coded drug-dosing guide – a system that completely eliminated all calculations – then the frequency of dosing errors was reduced to less than 10% [93,100,106]. This was, perhaps, unsurprising given the success of other calculation-free methods. The third finding was that inadequate training with the tape was associated with poor performance, both in weight estimation as well as drug dose determination. Formal training reduced, but did not eliminate, errors, however [69,88,109].

Since the drug-dosing information on the Broselow tape is incomplete and the evidence is compelling that additional refer-

ence material must be used, the drug dose information on the tape must be concluded to be uncertain value. The statement by a major training organisation that, "it is reasonable to use a body length tape with pre-calculated doses" may perhaps be adapted to stipulate that the use of supplementary reference material that eliminates calculations is essential [11].

5 Limitations

The limitations of this study are similar to what may be encountered in any meta-analysis [13,125]. The heterogeneity between samples generally makes meta-analysis difficult, but this was countered by the use of subgroup analysis. Furthermore, the between-study variance was similar to the within-study variance which suggested that the pooled data analysis was valid. The significant difference in outcomes between the weight estimation systems was the final validation of the power of the systems to deal with this variance.

The incomplete reporting of data and the generally poor quality of data presentation and statistical analysis in many articles was the major limitation for this study. The relative paucity of accuracy data and direct, paired comparisons between the Broselow tape and other systems may have restricted the breadth of findings to some degree.

6 Conclusions

Medication errors in children are common, occur more often in the Emergency Department, in sicker children and when treated by doctors with little experience in managing emergencies in children [126,127]. Nearly one hundred articles have been published on the Broselow tape over the last three decades, which have provided data for the following conclusions.

The Broselow tape does not estimate weight as accurately as the newer length- and habitus-based systems such as the Mercy method and the PAWPER tape. Length-based weight estimation, although significantly superior to age-based weight estimation, is simply not accurate enough. The Broselow tape is also significantly limited by its length, with no proven method for dealing with children "too tall for the tape".

The Broselow tape on its own does not provide sufficient drug-dosing information to be used without additional, comprehensive colour-coded drug administration information. The calculations needed to translate the milligram doses on the tape to volumes of drug dilution to administer create a major, debilitating source of errors.

The Broselow tape has also been shown to be vulnerable to user-errors in under-trained individuals. It would be beneficial to explore the role of incorporating training in weight estimation into simulation exercises as part of advanced life support courses

Conflict of interest

Professor Wells developed the PAWPER tape, but from which he derives no financial benefit.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.resuscitation.2017.09.026.

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