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Systematic Review

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Is there evidence that length-based tapes with precalculated drug doses increase the accuracy of drug dose calculations in children? A systematic review

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Objective The use of pediatric length-based weight estimation tapes with precalculated drug doses is advocated by major Advanced Life Support organizations, but concerns have been raised on the accuracy of these systems. The objective of this systematic review was to collect, review, evaluate, and create a synthesis of the current literature to establish whether there is high-quality evidence for use of length-based tapes in accurate drug dose administration. A further objective was to compare these tapes with other dosing aids.

Methods Eligible studies were identified and analyzed if they were peer reviewed, full text articles containing original data. Studies including any form of length-based precalculated drug dosing methodology in children aged 0 to 18 years were included.

Results Eighteen studies met the inclusion criteria. The most studied of the tapes was the Broselow tape in 16 studies (88.9%). When these tapes were used on their own without additional reference material, they produced a substantial number of potentially harmful dosing errors (>20% error). No tape was superior to another. Using the tapes was better than using no dosing aid but was inferior to using both comprehensive drug dosing guides and novel color-coded medication administration systems.

Conclusion There was no high-quality evidence that the use of length-based tapes with precalculated drug doses leads to accurate drug dosing. However, comprehensive drug dosing systems were more effective at reducing dosing errors than were length-based tapes on their own. The confounding effect of weight estimation accuracy on drug dosing accuracy has not been sufficiently studied.

Keywords Body weight; Broselow tape; Drug dosing; Patient safety

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Capsule Summary

What is already known

Length-based tapes with precalculated doses are commonly used in clinical practice and commonly taught in Pediatric Advanced Life Support courses.

What is new in the current study

This study shows a low level of evidence to support the use of length-based tapes with precalculated doses. Dosing aids that included comprehensive information reduce the risks of dosing errors compared with length-based tapes.

INTRODUCTION

Medical care during pediatric emergencies often involves drug dose miscalculations [1,2]. Drug errors are the most common cause of iatrogenic injury in these situations and occur significantly more often in the emergency department than any other area of the hospital [3–5]. Drug doses, fluid therapy, and cardioversion or defibrillation doses are generally based on total body weight in children. This means that both an accurate weight estimation as well as an accurate calculation of the drug dose, dilution, and volume-to-administer must be accomplished to avoid a medication error [6]. This is especially important in a critically ill or injured child or a malnourished child, who may already be physiologically vulnerable to harm [7]. Given the chaotic nature of pediatric resuscitations, the need for simple, quick, reliable methods of estimating weight and for accurately determining drug doses is evident [8]. In fact, medication errors during "code situations" are nearly 40 times more likely to lead to harm and just over 50 times more likely to result in death compared with those occurring during non-emergency care [9]. Since patient harm can be identified in at least 1% to 10% of errors in weight estimation or drug dose calculation, this is an important patient safety consideration [9–11]. Weight estimation errors and errors in drug dose calculation and administration appear to be equal contributors to the overall error rate [12].

One of the methods that was developed to provide both an estimate of weight as well as some basic drug dose information was the Broselow tape—a length-based tape preprinted with precalculated drug doses [8]. Introduction of this device was viewed as a milestone in pediatric resuscitation, as it provided a weight estimation and information on weight doses, defibrillation doses, and equipment sizes. More recent forms of length-based tapes with precalculated doses include the Handtevy tape and the National Park Service (NPS) emergency medical services (EMS) tape developed in the United States, and the Paediatric Emergency Ruler (PaedER) developed in Germany (Table 1) [8,13–15]. The Broselow tape is the most widely used and most studied of these tapes [16].

Major international Advanced Life Support training organizations have recommended the use of these tapes for at least the last 25 years [17,18]. These recommendations imply that these systems have been fully clinically validated and are supported by evidence of their accuracy and efficacy [17]. Furthermore, the guidelines recommend the use of length-based tapes when actual weight is unknown regardless of body habitus. These recommendations conflict with recent work that has raised concern on the accuracy of length-based tapes with precalculated doses [19–21]. Length-based tapes have come under increased scrutiny: they are not accurate in populations with a high prevalence of obese or of underweight children (or both) [20,22–25]. Their use may even be potentially harmful in malnourished children by causing overdoses [19,26]. It is important to review the published supporting evidence behind these systems to determine the most suitable approach for weight estimation and drug dosing during emergency care (for both in-hospital and out-of-hospital settings).

The main aim of this study was to systematically review the literature to establish whether there is high-quality evidence that the use of length-based tapes with precalculated doses leads to accurate drug dose determination. An important secondary aim was to identify data on the drug dosing accuracy of length-based tapes compared with other aids to drug dose calculation.

METHODS

This was a systematic review based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The PRISMA checklist can be found in Supplementary Material 1. The protocol for this systematic review is registered in PROSPERO (No. CRD42021253715). A literature search was con-

Table 1. Description and examples of length-based weight estimation tapes with precalculated doses

Tape name	History	Methods
Broselow tape	The Broselow tape was created by emergency medicine physician James Broselow and pediatric emergency medicine physician Robert Luten. Broselow first invented a home-made prototype version of the tape in 1985. The first commercial tape was created in 1988 using 1979 National Centre for Health Statistics data. The tape has since been updated every few years with newer growth chart data.	The Broselow tape relates a child's height, as measured by the tape, to their weight to provide medical instructions including medication dosages, the size of the equipment that should be used, and the shock dose when using a defibrillator. The Broselow tape is designed for children up to approximately 12 years of age who have a maximum weight of 36 kg. To use the Broselow tape effectively the child must be lying down. The tape should be stretched down the length of the child's body until it is even with their heels (not toes). The tape that is level with the child's heels will provide their approximate weight in kilograms and their color zone [8].
PaedER	The PaedER was developed in Germany. The weight and length distribution of German children was collected in a large national survey. Since the weight-for-length percentiles of German children were similar to data available in the United States, data provided by the CDC were used to determine the best length-weight estimation for the device.	The supine child is measured with the unfolded ruler from the heel to the head, where the height is displayed. Normal values for age, size of tracheal tubes, and weight-adjusted doses for the emergency drugs are provided on the tape [15].
NPS EMS tape	Based on the concept of the Broselow tape and with the aid of a grant from the National Park Foundation, this length-based pediatric emergency resuscitation tape specifically tailored to the NPS EMS Advanced Life Support scope of practice.	To use the tape, the tape is the run along the supine child's length from head to heel. The appropriate weight in kilograms can be read off at the level of the child's heel, together with corresponding medicine doses. A total of 32 medications, including cardiac drugs, narcotics, antibiotics, and many others are included on the tape [14].

PaedER, Paediatric Emergency Ruler; CDC, Centers for Disease Control and Prevention; NPS, National Park Services; EMS, emergency medical services.

ducted using MEDLINE, Scopus, ScienceDirect, Web of Science, and Google Scholar. Eligible studies published between January 1986 and July 2023 were identified using the following search terms: "(((pediatric OR children OR child OR infant) AND (emergency OR emergencies)) AND (weight estimation OR Broselow tape OR Handtevy tape OR length-based tapes OR precalculated drug doses)) AND (drug dosing OR medication dosing)." Citations from reference lists of articles and their MeSH (Medical Subject Headings) terms, conference presentations, and unpublished material were also reviewed to identify articles for potential inclusion. To minimize reporting biases, broad inclusion criteria were used, and multiple databases were used for the search, including the "grey literature." Studies were included from any setting (prehospital, emergency department, in-hospital) if they were peer reviewed, full text, published in English (or with an English translation), and contained original quantitative data on the accuracy of drug dosing using length-based tapes with precalculated doses. There was no limitation on the drugs studied or the study design. Studies that included any form of length-based precalculated drug dosing methodology in children aged 0 to 18 years were eligible for inclusion. Studies were excluded if they had outcomes other than drug dosing accuracy (Fig. 1). The authors independently screened articles for inclusion. Differences were resolved by discussion and consensus.

Once the article selection process was complete, data extraction was conducted by one researcher (PY), and the accuracy of data capture was independently reviewed by a second researcher (MW). The following data were extracted: study information (title, authors, publication date, number of patients, region of study), study design, drug dosing methods evaluated or compared, main findings, study limitations, and conclusions. Each included study was graded for risk of bias and quality of evidence using a modified Newcastle-Ottawa Scale (scored from 0 to 10) (Supplementary Material 2) [27].

The main outcomes of interest were the quality of the studies, the accuracy of calculated drug doses, the time taken to determine drug doses, and the completeness of the drug dose information presented (i.e., whether additional calculations were required to complete drug dosing, preparation, and administration).

RESULTS

There were no deviations from the published protocol. There were 18 studies included in the analysis (Fig. 1), the details of which are shown in Table 2 [12,14,28–43]. They were published from 2001 to 2023 and conducted in five countries, with 14 studies (77.8%) [14,28–31,33–36,38–42] originating in the United States. Half of the studies were conducted in an in-hospital environment [12,32,33,35,37,38,40,42,43], and half in an out-of-hospital setting or with EMS personnel [14,28–31,34,36,39,41]. There was a preponderance of simulation studies (14 studies, 77.8%) [12,14,29–38,40,41]. Only seven studies (38.9%) had evaluation of the dosing accuracy of a length-based tape as the primary objective [12,28,34,38,39,41,43]. Three studies (16.7%) attempted to differentiate between dosing errors caused by weight estimation errors and other factors [12,31,43].

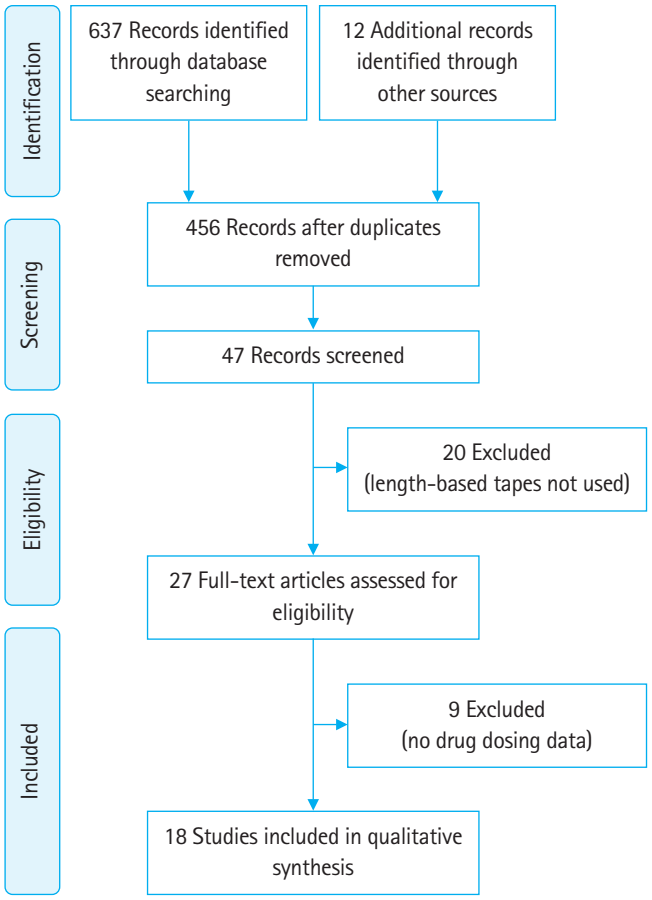

Fig. 1. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart for article identification and selection.

In four studies (22.2%), the performance of a length-based tape with precalculated doses was studied with no control and no comparative device or methodology [28–31]. A further four studies (22.2%) compared a length-based tape with precalculated doses against methods using comprehensive drug dosing information that eliminated the need for calculations [12,32–34]. Three more studies (16.7%) compared a length-based tape with precalculated doses against novel color-coded drug administration systems [35–37]. In seven studies (38.9%), a length-based tape with precalculated doses plus additional reference material was compared against a control consisting of either standard dosing guides or no dosing guide [14,38–43]. No study directly compared length-based tapes with precalculated doses.

The length-based tapes with precalculated doses were the Broselow tape, the NPS EMS length-based tape, and the PaedER. The most common was the Broselow tape, used in 16 studies (88.9%) [12,28–42].

The overall quality of the evidence from the studies, as assessed using the Newcastle-Ottawa Scale, was poor. One study (5.6%) [42] rated 2 points, five studies (27.8%) [28–30,33,41] rated 3 points, five studies (27.8%) [14,32,38,39,43] rated 4 points, one study (5.6%) [40] rated 5 points, five studies (27.8%) [31,34–37] rated 6 points, and a single study (5.6%) [12] received a 7-point rating. The details of the risk of bias for each study are shown in Fig. 2 [12,14,28–43].

There were too many studies with a high degree of heterogeneity to permit a quantitative synthesis of the data.

Length-based tape with precalculated doses vs. no comparative methodology

The Broselow tape was studied as a weight estimation and drug dosing tool in four studies with no comparative methodology [28–31]. In the first study by Hoyle et al. [28], a dosing error of >20% was used as an endpoint. This study had multiple significant exclusions (children too tall for the Broselow tape and obese or underweight children). Significantly, the accuracy of weight-based drug dosing was not consistently evaluated using a reference standard (actual measured body weight), which impacted on the validity of the dosing results. The study also found that large dosing errors were common, with 34.7% of doses exceeding a 20% error in the Broselow tape group and up to 60% of doses exceeded a 20% error in the group of children with cardiac arrest.

In the second study by Lammers et al. [29], a dosing error of >20% was also used as an endpoint. Participants experienced problems with drug dose conversions (converting a mg/kg dose to the volume of the diluted drug that should be administered), inaccurate volume measurements, recollection of doses, and calculation errors. The error rate was between 47% and 60%. The Broselow tape was used incorrectly 20% of the time, and weight estimation accuracy was not considered as a confounding variable.

The third study, also by Lammers et al. [30], evaluated the accuracy of drug administration using the participant's choice of the Broselow tape, the PediWheel First Responder, or the Pedi Stat App (QxMD Medical Software Inc), or combinations thereof, in simulated resuscitations. Multiple endpoints were evaluated. The Broselow tape was used incorrectly in 17% of children, and only 40% of doses were correctly determined using the tape. Participants had to simulate the administration of three medications, and the correct drug dose was administered in only 46%, 7%, and 33% of scenarios.

In the fourth study, by Hoyle et al. [31], the Broselow tape was studied with a comprehensive dosing reference, with no comparative group. This was a simulation study after a state-wide imple-

Table 2. Studies included in the review (n=18)

Study	Country	No. of participants	Study design	Drug dosing method	Primary objective	Endpoint	Comment	NOS
Vilke et al. [41] (2001)	USA	20 Participants (4 scenarios)	Simulation of cardiac arrest, out-of-hospital, observational study	Broselow tape vs. control (no drug dosing aid)	To evaluate [the paramedics'] ability to estimate weight with and without the Broselow tape.	Epinephrine dose deviation error < 50% achieved in 95% with Broselow tape and 90% with no dosing aid.	Very large ranges of doses accepted as accurate (within 50% error accepted). The accuracy of weight estimation was not considered.	***
Shah et al. [38] (2003)	USA	28 Participants (4 scenarios)	Simulation of two patients (burns and seizures), in-hospital, crossover trial	Broselow tape + color-coded sheets for precalculated doses vs. control (traditional resuscitation dosing reference material e.g., PALS Reference Card, the Harriet-Lane handbook)	To estimate the decrease in deviation from recommended medication doses associated with use of a pediatric intervention standardization system in the acute setting.	Accuracy of drug doses. The median deviation from recommended dose range for the medication prescribed in the Broselow tape group scenarios was 24.4% lower than in the control scenarios. Participants favored the Broselow tape and color-coded material.	The Broselow tape was used with additional reference material. The confounding effect of the accuracy of weight estimations was not considered. Learning effects were a potential confounding factor.	****
Kaji et al. [39] (2006)	USA	145 Children	Real-life study of pediatric cardiac arrest, out-of-hospital, before-and-after study	Broselow tape + precalculated drug dosing charts vs. control group (no drug dosing guide, Broselow tape used in 59% of children, other details of weight estimation methods unspecified)	To describe the change in the rate of epinephrine dosing errors in the treatment of pediatric patients after a program in which paramedics were required to use the Broselow tape.	Accuracy of epinephrine doses. In the control (before) group, 28% received the correct first dose, 44% received a first dose within 20% of the correct dose. In the 59% of the children that had been measured with the Broselow tape, the doses were correct in 27% of instances. The doses were close (within 20% of the exact dose) for 37.5% of the children. In the intervention (after) group (Broselow tape + additional reference material), 57% of the children received the correct dose and 65% of the children received a dose within 20% of the exact dose.	Accuracy of dosing was not controlled for when compared to actual weight.	****
Gaca et al. [40] (2007)	USA	19 Participants (2 scenarios)	Simulation of contrast-induced anaphylaxis, in-hospital, case-control study	Broselow tape + color-coded precalculated drug dosing charts vs. control (no resuscitation aid)	To prospectively develop and test a simulation model for assessing radiology resident preparedness for a pediatric life-threatening event in the radiology environment.	Dosing accuracy and time to administer treatment. Times to administer treatment were slightly faster with the use of resuscitations aids. There was no difference in the dosing accuracy of epinephrine.	This was a small study, not powered to detect any reasonable difference in doses. Learning was a major limitation. Dose accuracy was not controlled for actual weight.	*****

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Table 2. (Continued)

Study	Country	No. of participants	Study design	Drug dosing method	Primary objective	Endpoint	Comment	NOS
Fineberg and Arendts [37] (2008)	Australia	16 Participants (6 scenarios)	Simulation of cardiac arrest, seizures, rapid sequence intubation, in-hospital, crossover study	Broselow tape vs. standardized volume per weight-based formulations method	The study proposed a standardized volume per weight-based dose reformulation of resuscitation and critical care medications (reformulated to 0.1 mL/kg) and compared it with the Broselow tape with respect to time to drug delivery and the incidence of dosage error.	The time to reconstitute emergency drugs, ready for administration. The standardized volume per weight-based dose formulation reduced by more than 50% the median time to medication delivery as compared with the Broselow tape.	The Broselow tape was not actually used, and weight estimation accuracy was not taken into account. Dose accuracy was not controlled for actual weight. The standardized system that was studied is not commercially available and has not been subsequentially validated.	******
Feleke et al. [33] (2009)	USA	16 Nurses (20 dose orders per nurse, 320 total dose orders)	Simulation, in-hospital, preintervention-and-postintervention study	Standard methods of drug dose calculations (including Broselow tape) vs. a color-coded comprehensive drug dosing guide.	To compare the performance of current systems in place for preparation and administration of pediatric medications in community emergency departments to the color-coded medication safety system.	Time-to-dose calculation completion, dilution calculations, error rates and detection of dose errors. Lower dose error rates (2.6% vs 25.6%), dilution error rates (0.6% vs 35.6%) along with faster dose calculation times were found with the color-coded system.	Insufficient information was provided on whether the Broselow tape was actually used to aid calculations in the standard method group. No assessment of weight estimation and its impact on doses was included in the study. The color-coded system that was studied is not commercially available.	***
Pinchevsky et al. [42] (2010)	USA	54 Participants (only 4 included in the analysis, 10 drug doses analyzed)	Real-life, in-hospital, retrospective observational study	Broselow tape vs. doses calculated from ideal body weight and actual body weight	Dose calculations using three variations of patient weight estimates (ABW, IBW, and the Broselow tape) were compared to administered doses of cardiopulmonary resuscitation medications in overweight and obese children to assess for differences in dose.	Accuracy of drug dose administered. A total of 40% doses calculated with ABW and 80% doses calculated with IBW and 80% doses recommended by the Broselow tape differed by more than 20% from the administered dose. The largest dosing differences were observed upon comparison of the correct dose versus the dose recommended by the Broselow tape.	There were many exclusions in this study. Only overweight children were included (this was the target population of the study). The Broselow tape was not actually used, this was a modelling study.	**
Hoyle et al. [28] (2012)	USA	230 Patients (621 drug doses)	Real-life, out-of-hospital, retrospective observational study	Broselow tape	To determine the frequency and magnitude of medication dosing errors in children treated by paramedics and determine the frequency of medication dosing errors in patients for whom the use of the Broselow-tape was documented.	Dosing errors >20%. Dosing errors occurred in 34.7% of children. Errors larger than 20% were common.	Multiple significant exclusions including children too tall for Broselow tape and obese and underweight children (5% of sample). Either the Broselow tape or actual weight was used as the basis for determining accuracy of dosing, which was a major limitation.	***

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Table 2. (Continued)

Study	Country	No. of participants	Study design	Drug dosing method	Primary objective	Endpoint	Comment	NOS
Lammers et al. [29] (2012)	USA	45 EMS crews	Simulation of seizures and respiratory arrest, out-of-hospital, prospective observational study	Broselow tape	To determine the most common, underlying causes of clinically significant errors committed by teams of prehospital providers, and associated error-producing conditions, during a standardized, simulated pediatric emergency.	Dosing errors >20%. Errors in anticonvulsant doses of 47% to 60% of doses of various drugs. Participants experienced problems with drug dose conversions and calculations.	The Broselow tape was used incorrectly 20% of the time. Errors were greater in the 20% of cases in which the participants did not use the Broselow tape. Weight estimation accuracy was not taken into account as a confounder.	***
Lammers et al. [30] (2014)	USA	194 Participants in 60 teams (1 scenario)	Simulation of cardiac arrest, out-of-hospital, prospective observational study	Broselow tape	To identify errors of prehospital care providers and underlying causes during a simulated infant cardiopulmonary arrest.	Accuracy of drug administration using Broselow tape. Broselow tape not used or used incorrectly in 17% of children. Only 40% of participants gave the correct dose of epinephrine.	Only a single scenario used. Weight estimation accuracy was not considered as a confounder.	***
Campagne et al. [14] (2015)	USA	20 Participants (2 scenarios)	Simulation of febrile seizures and anaphylaxis, out-of-hospital, crossover trial	NPS EMS tape vs. control (standard medication dosing methods, asking parents to estimate weight, age-based calculations)	To evaluate the accuracy of medication dosing and the time to medication administration in the prehospital setting using a novel length-based pediatric emergency resuscitation tape.	Accuracy of drug dosing and the time taken to determine the doses. The only errors that occurred were in the control group. A total of 12% errors made in the control group, 0% errors in the intervention group. The mean time to determination of acetaminophen, midazolam and diphenhydramine doses was shorter in the intervention group than the control (28.6 sec vs. 50.6 sec, 8.6 sec vs. 27.0 sec, 13 sec vs. 37.6 sec respectively). There was no difference between the groups in the time required to determine the dose of epinephrine.	Weight estimation not studied; estimated weight assumed to be correct. Multiple comparators (dosing aids) in the control group.	****

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Table 2. (Continued)

Study	Country	No. of participants	Study design	Drug dosing method	Primary objective	Endpoint	Comment	NOS
Moreira et al. [35] (2015)	USA	10 Participants (2 scenarios)	Simulation of cardiac arrest, in-hospital, crossover trial	Color-coded prefilled syringes vs. Broselow tape with conventional vial-to-syringe system for drug delivery	To evaluate novel, prefilled medication syringes labeled with color-coded volumes corresponding to the weight-based dosing of the Broselow tape, compared with conventional medication administration, in simulated pediatric emergency department resuscitation scenarios.	Accuracy of drug dosing and the time taken to determine the doses. Using the conventional dosing method, 90% made at least one dosing error and 70% made one or more critical dosing errors. Of the 118 doses administered, 31 (26%) were dosing errors, with 20 (17%) classified as critical dosing errors (there were 17 critical overdoses and three critical underdoses) Using the color-coded method, 40% made at least one dosing error and 0 made a critical dosing error. Of the 123 doses administered, five (4%) were classified as dosing errors and 0 (0%) as critical dosing errors	Weight estimation accuracy not evaluated or considered as a confounder. The color-coded system that was studied is not commercially available.	******
Stevens et al. [36] (2015)	USA	10 Participants (4 scenarios)	Simulation of cardiac arrest, out-of-hospital, crossover trial	Prefilled color-coded syringes vs. Broselow tape with conventional vial-to-syringe system for drug delivery	To evaluate novel, prefilled medication syringes labeled with color-coded volumes corresponding to the weight-based dosing of the Broselow tape, compared to conventional medication administration, in simulated prehospital pediatric resuscitation scenarios.	Accuracy of drug dosing and the time taken to determine the doses. With the Broselow tape 80% of participants made one or more critical dosing errors, with 70% making one or more dosing errors. With the prefilled color-coded medication syringes 0% critical dosing errors were made, with 30% of participants making one or more dosing errors.	Weight estimation accuracy not evaluated or considered as a confounder. The color-coded system that was studied is not commercially available.	******
Rappaport et al. [34] (2016)	USA	80 Participants (4 scenarios)	Simulation of cardiac arrest and hypoglycemia, out-of-hospital, prospective randomized simulation study	Broselow tape vs. Handtevy tape + a color-coded comprehensive drug dosing guide	To compare two length-based tape systems for dosing errors and time to medication administration in simulated prehospital scenarios.	Accuracy of drug dosing and the time taken to determine the doses. Dextrose: more errors with the Broselow tape (63.8%) compared to the Handtevy (13.8%), time to administration was longer with the Broselow tape (220 sec vs. 173 sec). Epinephrine: both tapes performed similarly with an overall error rate of 21.3% for the Broselow tape and 16.3% for the Handtevy tape and time to administration of 89 sec vs. 91 sec, respectively.	Dose accuracy not compared to actual weight-based doses. Weight estimation accuracy not evaluated or considered as a confounder.	******

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Table 2. (Continued)

Study	Country	No. of participants	Study design	Drug dosing method	Primary objective	Endpoint	Comment	NOS
Larose et al. [32] (2017)	Canada	40 Participants (4 scenarios)	Simulation, in-hospital, crossover study	Reference book providing weight-based precalculated doses vs. Broselow tape used for weight estimation + milligram per kilogram dose card	To evaluate whether a clinical aid providing precalculated medication doses decreases prescribing errors among residents during pediatric simulated cardiopulmonary arrest and anaphylaxis.	Accuracy of drug dosing. Only 56% of scenarios were completed without prescribing errors: 56% in the intervention group and 56% in the Broselow tape group. For bolus medications, 64.4% of the scenarios were completed with no prescribing errors: 69% in the intervention group and 60% in the Broselow tape group. For infusion medications: medication errors occurred in 4% of scenarios in the in the intervention group and 22.4% in the Broselow tape group.	Neither system made use of comprehensive dosing information. Dose accuracy not compared to actual weight. Weight estimation accuracy not evaluated or considered as a confounder.	****
Kaufmann et al. [43] (2018)	Germany	Retrospective: 39 patients Prospective: 60 patients	Real-life, in-hospital, before-and-after study	PaedER height-based tape vs. conventional dosing methods	The study developed a simple height-based dose recommendation system and evaluated its effectiveness in apreintervention-post intervention trial.	Accuracy of drug dosing (deviation from recommended dose >300%). Medication error rates were 22% in the preintervention and 2.2% in the postintervention group. The use of the PaedER prevented 90% of errors when compared with the control group.	Before-and-after study with mixed retrospective and prospective data. Very broad definitions of dosing errors. Very small numbers of participants.	****
Hoyle et al. [31] (2020)	USA	15 crews (4 scenarios)	Simulation, out-of-hospital, prospective observational study	Standard equipment (Broselow tape + pediatric dosing reference)	To evaluate the rate of medication errors, including errors of omission and commission, after implementation of a state-wide pediatric dosing reference.	Accuracy of drug dosing (deviation from correct dose >20% considered an error). Errors occurred in between 27.1% and 44% of cases, with a substantial number of 10-fold errors. Errors of omission were common.	Weight estimation accuracy was evaluated as a confounder and identified as the prime cause of error in one-third of cases. Weight estimation was performed on manikins, therefore the impact of weight estimation errors in underweight and obese children was not determined.	******

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Table 2. (Continued)

Study	Country	No. of participants	Study design	Drug dosing method	Primary objective	Endpoint	Comment	NOS
Wells and Goldstein [12] (2020)	South Africa	32 participants (8 scenarios)	Simulation of eight different scenarios, in-hospital, prospective observational study	Broselow tape vs. PAWPER XL tape + comprehensive dosing guide vs. control (no dosing guide)	To evaluate the accuracy of drug dose calculations using the Broselow tape, the PAWPER XL tape plus its companion drug dosing guide, a custom-designed mobile phone app and no drug dosing aid (control group).	Accuracy of drug dosing and the time taken to determine the doses. The PAWPER XL tape group had significantly fewer dosing errors and critical dosing errors than the Broselow tape and the control groups. The Broselow tape group was significantly more accurate than the control group. Times to complete calculations were significantly faster in the PAWPER XL group than the other groups.	Both weight estimation inaccuracies as well as dose calculation errors led to the very poor performance of the Broselow tape, and even worse in the control group. Accuracy of Broselow tape doses compared to doses correct for actual weight, not estimated weight. Control group doses were controlled for weight estimation to eliminate weight estimation as a confounder influencing dosing inaccuracies.	*******

Basic information is shown for each study, including the NOS rating for study quality (maximum 10 stars possible). Comprehensive drug dosing guides were defined as methods that provide detailed information on drug doses and preparation so that no calculations are required by the user. Novel color-coded systems were defined as Broselow color-coded devices of any type, which determine the drug dose to be administered, eliminating the need for calculations.

NOS, Newcastle-Ottawa Scale; PALS, Pediatric Advanced Life Support; ABW, actual body weight; IBW, ideal body weight; NPS, National Park Service; EMS, emergency medical services; PaedER, Paediatric Emergency Ruler.

mentation of the use of the Broselow tape plus a comprehensive pediatric dosing guide. Errors of both weight estimation or drug dilution and delivery calculations caused a dosing error in more than 30% of simulations. Tenfold errors were common. The use of the comprehensive dosing reference reduced, but did not eliminate, dosing errors, even when the effects of weight estimation errors were considered.

Length-based tape with precalculated doses vs. comprehensive dosing aids

A study by Larose et al. [32] compared a reference book providing weight-based precalculated doses with a milligram per kilogram dose card (using the Broselow tape as a weight estimation tool). They found no difference in drug dosing errors, with an error rate of 44% for both intervention and control groups. In another study by Feleke et al. [33], the authors found significantly lower dosing error rates (2.6% vs. 26.5%), lower dilution calculation error rates (0.6% vs. 35.6%), and faster dose calculation times when using a comprehensive dosing aid compared to using the Broselow tape alone. A study by Rappaport et al. [34] compared drug dosing accuracy of the Broselow tape and the Handtevy tape (with its companion comprehensive dosing guide). The systems performed similarly with dextrose administration, with an error rate of 21.3% for the Broselow tape group and 16.3% for the Handtevy group. With epinephrine administration, the Broselow tape had a higher error rate of 63.8% and a slower administration time compared to the Handtevy tape, which had an error rate of only 13.8%. Wells and Goldstein [12] compared the Broselow tape, the PAWPER XL tape (with a companion dosing reference), and a control group (with no dosing aid) and reported that the PAWPER XL had the fewest errors and fastest times to determine doses. The Broselow tape had a very high error rate of 52.3% but did outperform the control group.

Length-based tape with precalculated doses vs. novel color-coded systems

Color-coded syringe systems were uniformly superior to length-based tapes with precalculated doses (Table 3) [35–37]. In a study by Moreira et al. [35] of 123 doses administered in a novel color-coded group, only five (4.1%) involved errors, of which none (0%) were critical. Of the 118 doses administered in the Broselow tape group, 31 (26.3%) were classified as errors and 20 (16.9%) as critical errors. In a second study, by Stevens et al. [36], there were no critical errors among five dosing errors of the 59 doses (8.5%) given in the novel color-coded system group. A total of 33 of the 62 doses (53.2%) determined using the Broselow tape dos-

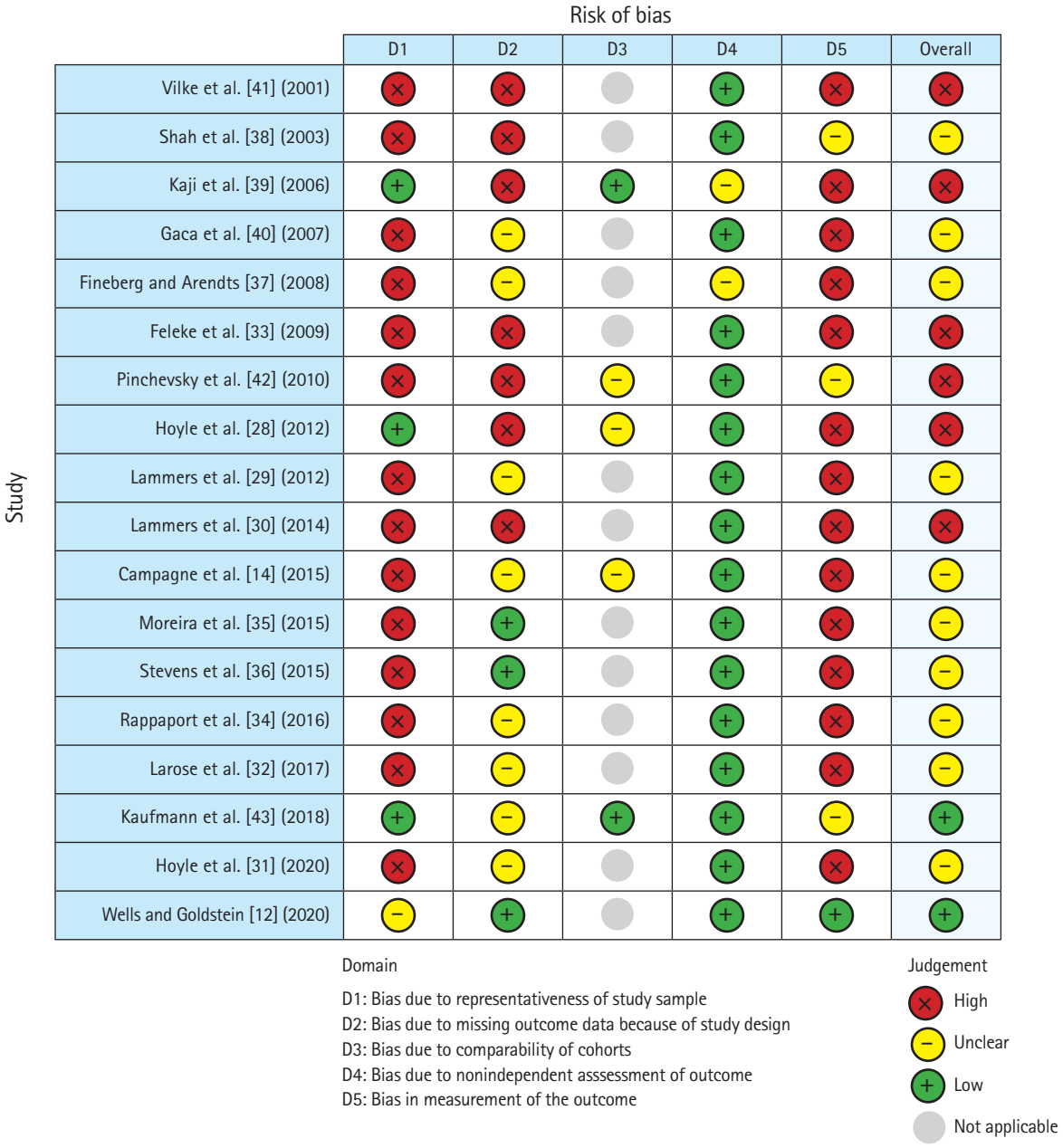

Fig. 2. Assessment of risk of bias for the included studies.

Table 3. Color-coded systems and devices

Type of color-coded system	Description
Per kilo doser (PKD) [37]	This device contains 15 compartments to accommodate 15 medications. Each compartment is equivalent in height and depth. The various milliliters per kilogram dosing of the medications are determined by the respective compartment widths. Compartment widths vary proportionately based on predetermined, calculated milliliters per kilogram values. Multiple lines are drawn across the dispenser, which correspond to the patient's weight. At the base of each compartment is a hole through which medication may be withdrawn. A needle is inserted into the hole and medication is withdrawn to the weight marking appropriate for the patient. No calculations are required to be performed. The PKD is also shaded with various colors to correspond to those on the Broselow tape. The authors provided limited information on how this device is filled or stored for potential use. This is not a commercially available device and has never been subsequently evaluated.
Color-coded, prefilled syringes [35,36]	These syringes are labeled with the name of medication and calibrated using the Broselow color-coding system. The child is measured using the Broselow tape to determine the color zone into which they fall. Medication is drawn up into the color-coded syringe to the appropriate color zone marked on the syringe. This volume is then administered. This is not a commercially available device and has not been subsequently evaluated.

es involved errors, with 24 (38.7%) classified as critical. In a study by Fineberg and Arendts [37], the Broselow tape was compared to a standardized volume per weight-based drug administration system. The percentage of dosing errors with the Broselow tape across three scenarios was marginally greater: 8% vs. 0%, 0% vs. 0%, and 8% vs. 2%.

Length-based tape with precalculated doses plus additional reference material vs. control

In three studies [38–40], the Broselow tape was used in conjunction with additional reference materials and was compared to a control group using no dosing aid. In all three studies, the Broselow tape outperformed the control group (with no dosing guide). The dosing error was lower in the Broselow tape group than the control group by 24.4% in a study by Shah et al. [38]. In another study by Kaji et al. [39], the correct doses were received in 57% of the Broselow tape group and 28% of the control groups. Of the doses received, 65% in the Broselow tape group and 44% in the control group were within 20% of the correct dose. In the last study, by Gaca et al. [40], there was no difference in drug dosing accuracy but a faster time to administration in the Broselow tape group.

Length-based tapes with precalculated doses without additional material vs. control

In four studies [14,41–43], length-based tapes (without additional references) were compared to a control group (no drug dosing aid or conventional methods of drug dosing). A study by Vilke et al. [41] reported a dose error $<50\%$ in 95% of cases with the Broselow tape and of 90% with no dosing aid. The second study, by Pinchevsky et al. [42], essentially compared the accuracy of doses by the Broselow tape with doses calculated from ideal body weight and actual body weight in obese children. The accuracy of drug doses administered was 40% when calculated based on actual body weight and 80% doses when calculated from ideal body weight. A study comparing the NPS EMS length-based pediatric emergency resuscitation to a control [14] found dosing errors in 0% of simulations in the tape group and 12% in the control group. In the study by Kaufmann et al. [43] on the PaedER versus control, the rate of deviation from the recommended dose was 2.2% in the PaedER group and 22% in the control group.

DISCUSSION

The certainty of evidence supporting the use of length-based tapes for drug dosing is not clear. This is important as these tapes are advocated for use in clinical practice and are commonly taught in Pediatric Advanced Life Support (PALS) courses. This is a critical patient safety matter. The first aim of this study was to determine the existing evidence base for the use of length-based tapes for drug dosing purposes. One of the major findings of this review was how poorly this has been studied, and that there is a low level of certainty in the evidence supporting their use. The lack of prospective clinical studies was noteworthy [44]. The second aim in this study was to compare the accuracy of length-based tapes against other methods of drug dose guidance. There were three main findings in this respect. First, when using length-based tapes alone, dosing accuracy was always inferior to that using comprehensive drug dosing guides. Second, using a length-based tape was better than using no dosing aid, but large dosing errors were prevalent. Third, using length-based tapes was always inferior to using novel color-coded medication administration systems. This last point is largely moot from a practical perspective, as none of these systems have been evaluated in subsequent studies and are not generally available for clinical use.

The studies included in this review showed that, in any setting when length-based tapes were used without comprehensive reference material, they produced a substantial number of potentially harmful dosing errors (doses $>20\%$ different from the correct dose). This has been a recurring criticism of these tapes. These errors are as a result in errors in weight estimation, as well as errors resulting from drug dose calculations because of the incomplete drug dosing information on the tapes [19,21,45]. Both of these root causes are important and must be considered [12].

Weight estimation errors

Several major US patient safety organizations have determined that incorrect estimation of weight is one of the key causes of medication errors [10,11]. Approximately 65% to 75% of weight estimation errors greater than 10% reach the patient in terms of dose errors, and patient harm can be identified in at least 10% of these incidents [10,11,46]. In this review, most of the included studies did not control well for weight estimation errors caused by the length-based tapes. Since both weight estimation errors and drug dose calculation errors contribute to final dosing errors, this was an important deficiency [12]. However, three studies [12,31,44] did provide some insight into the impact of weight estimation errors on the final drug dose accuracy, suggesting that these errors account for between one-third and one-half of patient dosing errors, though even this may be an underestimate of the risk of errors. Many studies focused on weight estimation accuracy have established that length-based tapes underestimate

the weight of overweight and obese children and overestimate the weight of underweight or malnourished children, with errors of 30% to 50% not uncommon [20,27,45,47]. Weight estimation studies have also shown that parental estimations of weight, as well as the newer length- and habitus-based methods (such as the PAWPER XL tape and the Mercy method), are significantly more accurate than length-based tapes [27,45,47].

Drug dose calculation errors

Since the Broselow and similar tapes present limited dosing information, there is a risk of errors in the calculation of the dilution and the final volume to be administered. This review showed that these errors (independent of weight estimation errors) occurred in 13% to 36% of doses [12,31,44]. Thus, of all dosing errors that reach the patient, about 20% occur from weight estimation errors, about 25% from dosage calculations, and about 50% from dilution calculations and administration of the medication [6,9]. The need to reduce errors at each stage of the process is important [48].

Comprehensive dosing guides

It was evident from this review that the failure to use a comprehensive dosing aid is associated with very large dosing errors, with a resulting significant risk of patient harm. While it was clear that comprehensive dosing aids resulted in the most accurate dosing, this accuracy would depend on accurate weight estimation and drug preparation and administration in a clinical setting [49].

International guidelines on weight estimation and drug dosing

The use of length-based tapes with precalculated doses has been recommended by some of the most influential international organizations. The PALS course and the Advanced Trauma Life Support (ATLS) course have included these recommendations since at least the mid-1990s [18,50]. However, from the data in this systematic review, these guidelines have limited evidentiary support. From a drug dosing point of view, the evidence does not justify the advocacy for use of length-based tapes other than as a final resort if no other aid is available. From a weight estimation perspective, many authors have questioned the accuracy and safety of the tape given the current increasing prevalence of obesity in the pediatric population, as well as the potential for harmful overdoses in children from a low-income setting [51–53]. Furthermore, better weight estimation systems are available [27,47].

The most recent international guidelines, released in 2020, have acknowledged that length- and habitus-based weight estimation methods are more accurate than length-based tapes [54,55]. They also acknowledge that dosing aids reduce dosing and administration errors and should be used [54,55]. The recommendation for the use of length-based tapes is still included but is considerably weakened from previous guidelines. However, this may take some time to translate into clinical practice guidelines.

The international guidelines and their corresponding courses would benefit from a revision to address three main, interrelated points: comprehensive drug dosing systems should be used in conjunction with the most accurate weight estimation systems due to the high prevalence of both underweight and obese children globally, drug dosing guidelines should address management of each of these groups of children, and training in weight estimation and drug dosing procedures are an essential part of an error reduction strategy.

Limitations

The number of eligible studies, despite very broad inclusion criteria, was very low. This, together with the low level of the evidence from the studies, limited the conclusions that could be drawn from this study regarding comparisons between methods. In addition, most of the studies included Broselow tape, with few on the other length-based weight estimation tapes. However, the lack of available evidence itself addressed the primary aim and was sufficient to cast doubt on current practice.

Conclusions

In this study, we found no high-quality evidence that the solo use of length-based tapes with precalculated doses leads to accurate drug dose determination. These tapes offer only incomplete drug dose information to the user. The available evidence suggests that these devices do not achieve an adequate degree of accuracy and could potentially put children at risk of harm if they are used alone. In addition, important confounders, such as the contribution of weight estimation inaccuracy to dosing error, have not been adequately explored or quantified.

Compared with other methodologies, the use of length-based tapes produced more accurate drug dosing than when no aid was used. However, the use of comprehensive dosing systems (with information on precalculated dosage, mixing instructions, and volume-to-administer) was more accurate than the use of length-based tapes alone.

We found very limited evidence on length-based tapes with precalculated drug doses other than the Broselow tape. The findings of this study cannot, therefore, be generalized to include

other such tapes. However, the lack of supporting evidence was itself an important finding and suggests caution when using these devices.

Although no high-level evidence is available, it is reasonable to conclude that comprehensive dosing systems should be used together with the most accurate weight estimation systems during pediatric resuscitation in preference to length-based tapes alone.

ARTICLE INFORMATION

Author contributions

Conceptualization: MW; Data curation: PY; Formal analysis: all authors; Methodology: MW; Supervision: MW; Writing– original draft: PY; Writing–review & editing: all authors. All authors read and approved the final manuscript.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Data availability

Data analyzed in this study are available from the corresponding author upon reasonable request.

Supplementary materials

Supplementary Material 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 checklist.

Supplementary Material 2. The Newcastle-Ottawa Scale adapted for dosing accuracy studies.

Supplementary materials are available from https://doi.org/10.15441/ceem.23.110.

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