An analysis of the appropriateness of the statistical methodology and data reporting used in paediatric weight estimation studies - A systematic review.

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A research report submitted to the Faculty of Health Sciences of the University of the Witwatersrand, Johannesburg, in partial fulfilment for the Degree of Masters of Medicine in Emergency Medicine

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This research report is being submitted for the Degree of Master of Medicine in Emergency Medicine at the University of the Witwatersrand, Johannesburg.

Diana Silva Carvalhal

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To my amazing husband, Sergio, who pushed me and encouraged me through this study. Your knowledge in excel has never been more appreciated. Your unwavering love and dedication to Diogo and I is remarkable and without it I would be unable to achieve what I have.

To my Diogo, my greatest blessing, you inspire me and motivate me. You represent the need for research such as this, so that children just like you may benefit from improved and safe medical care.

LIST OF TABLES AND FIGURES

ABREVIATIONS

BMI- Body Mass Index
DC-Diana Carvalhal (primary author)
DWEM- Devised weight estimation method
EBM- Evidence Based Medicine
ICC-Intraclass Correlation
IRB- Institutional review board
Kg- Kilogram
MW- Mike Wells (supervisor)
PAWPER-Paediatric Advanced Weight prediction in Emergency Resuscitation
PRISMA- Preferred Reporting Items for Systematic Reviews and Meta-Analyses

ABSTRACT

Background: Accurate paediatric weight estimation systems are critical for safe drug dosing in emergency care. However, the validity of many of the studies evaluating the accuracy of these systems has been questioned. The objective of this systematic review was to analyse the appropriateness of the study design, statistical methodology and data presentation in published paediatric weight estimation studies.
Methods: Studies that evaluated paediatric weight estimation systems, published between January 1986 and January 2023, were identified. Data extraction included publication details, study types, weight estimation methods under investigation, statistical methods, and subgroup analyses. Study quality and risk of bias was evaluated using the Newcastle-Ottawa tool.
Main results: The review included 193 articles spanning a 32-year period. Only about a third (64/193 (33.2%)) of the studies employed comprehensive and appropriate statistics and metrics for evaluating weight estimation methods, while 81/193 (41.5%) relied solely on inappropriate metrics and statistics. Subgroup analyses were not performed in 137/193 (71.0%), with appropriate subgroup analyses only reported in 13/193 (6.7%) of studies. Poor sampling methods, inadequate inclusion/exclusion criteria, insufficient statistical analysis, suboptimal data reporting, and inadequate use of subgroup analyses frequently compromised the study findings.
Conclusions: This study identified major limitations in the design, methodology, and data analysis of a significant proportion of paediatric weight estimation studies. These limitations had a major impact on the validity of many of the studies. The need for specific guidelines on study design, statistical methodology, subgroup analyses, and data presentation in this field is evident.

Key words: paediatric weight estimation, statistical methodology, PAWPER tape, Broselow tape, Mercy method

INTRODUCTION

Background

When treating a critically ill child, measurement of actual weight is often not a feasible option. Clinicians need a quick, reliable, and easy-to-perform method of weight estimation (1). The preferred method should be the one with the best level of evidence and most appropriate for the population (2). It seems irrational to use a weight estimation system that has been demonstrated to be inaccurate, however such systems are currently still in use (3).

As early as 1954, Weech published a paper highlighting a variety of age formulas for prediction of paediatric weight based on data from two textbooks on paediatrics (4). He also explored the notion of weight as a function of height and developed equations to predict weight as a function of height or length. It wasn't until 1986 that Garland *et al* published the first paediatric weight estimation method comparison study and proposed the Devised Weight Estimation Method (DWEM) based on height/length and body habitus (5). Since then, numerous other methods of paediatric weight estimation have been described.

Medical research is crucial to the development of safe and effective treatment modalities. As Sacket *et al* wrote, "Evidence based medicine (EBM) is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients" (6). Therefore, EBM is paramount for the formulation of clinical decisions and policies. If individual studies are biased or methodologically flawed, their results may be misinterpreted and reach erroneous conclusions (7, 8). It is the responsibility of researchers and journals to conduct and publish research that is of a high quality.

In relation to weight estimation studies, predictive validity is the outcome that is essential to prevent adverse events in the emergency department. Predictive validity is the concept that most closely resembles true validity as it is the "comparison between the results from an experimental test and a reference criterion standard"(DJ.

Karras, 1997)(9). The reference criterion in this case is weight (kg) measured on a calibrated scale. How closely the results of the experimental test and the reference criterion are associated will be a measure of the tests validity and in order to correctly assess the performance of the test method, the appropriate statistical tools must be used (10-12). There is concern that many studies in the field of paediatric weight estimation analyse and report data either incompletely or incorrectly (3).

Importance

It is important for a clinician to be able to rely on information given in a publication. However, simply accepting this information as fact can be hazardous. The study design, methodology, and data presentation used for the analysis all influence the validity of a study (10). If these are not correct there is a risk of drawing incorrect conclusions from papers with major flaws. It is necessary to adhere to research methodologies that provide a solid basis for evidence-based decisions (13). An understanding of this is important for clinicians, researchers, journal reviewers and editors, and decision-makers in clinical leadership.

High quality method comparison studies are necessary to test weight estimation systems against a gold standard, and against each other. The goal of these studies is to establish whether the performance of a system is acceptably accurate. To achieve this, the new system should meet predefined standards to prove its utility in the target population. Performance will be directly related to measures of bias, precision, and accuracy. This is crucial as a paediatric weight estimation system needs to provide accurate estimation of paediatric weight, to provide safe emergent treatment of paediatric patients when measured weight on a calibrated scale is not possible(14).

Goals of this investigation

The primary goal of this systematic review was to review and synthesize the data on the statistical methods and data presentation used in published paediatric weight estimation studies. The secondary goal was to determine the appropriateness of this data presentation and statistical analysis. These goals would inform the need for, and potential content of, specific guidelines for paediatric weight estimation studies.

METHODS

Search strategy

This study was based on the PRISMA methodology. Electronic databases (Medline, Science Direct, and Scopus) and online search engines (Google and Google Scholar) were searched for eligible studies published between January 1986 and January 2023. The search terms: “paediatric weight estimation”, “weight estimation children”, “weight estimation methods”, “age-based formulae”, “parental estimates of weight”, “PAWPER tape”, “Mercy method” and “Broselow tape”’ were used. The citation lists of the papers generated by the search were also searched for additional relevant articles. To minimise reporting bias and to ensure maximal capture of relevant studies broad inclusion criteria were utilised in the search. This included searching for studies in the “grey literature”, namely letters to the editor, abstracts, dissertations/doctoral theses, research reports and blogs.

Study selection and eligibility criteria

Studies considered for inclusion met the following criteria: research studies on any weight estimation methods in children (age≤20 years) with original data; full length studies published in peer-reviewed journals; studies written in English or with English translations. Studies that did not meet the inclusion criteria and studies that were irrelevant to paediatric weight estimation methods were excluded. Once the identification process was complete and duplicates and irrelevant citations were removed, the authors independently screened the remaining articles for the inclusion and exclusion criteria. Any disagreement between the authors was resolved with discussion (see Figure 1).

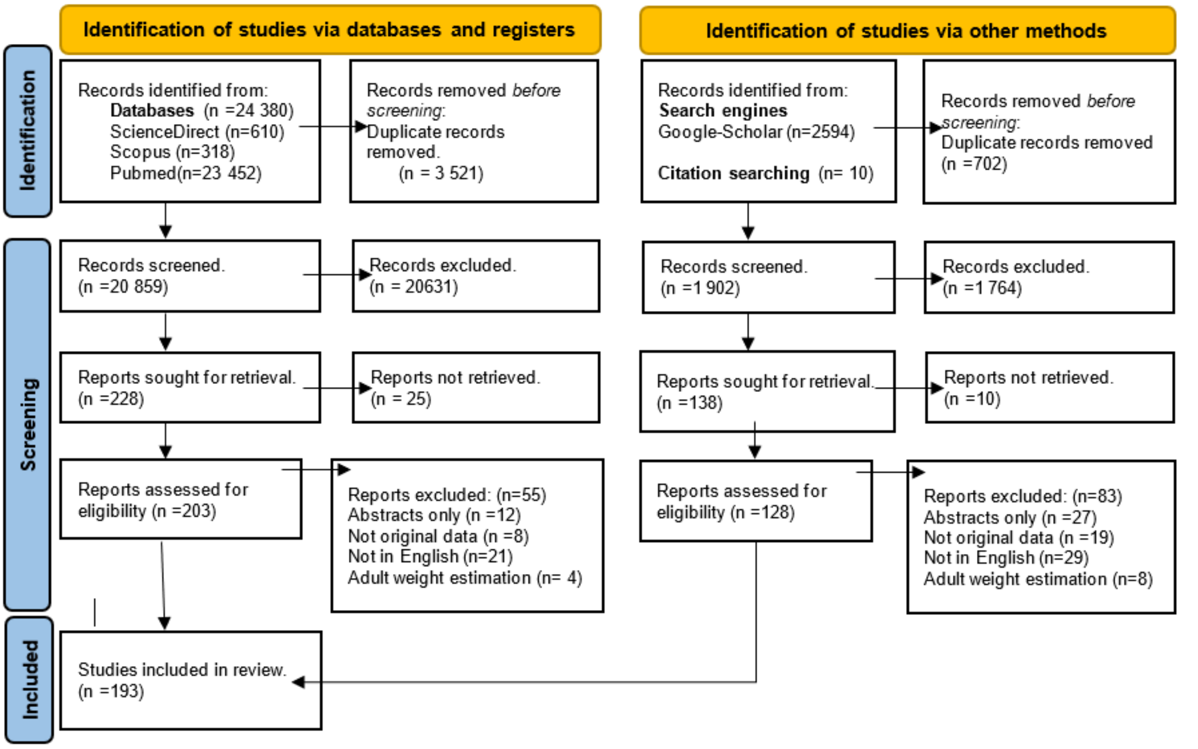


Figure 1- PRISMA flow diagram of the study selection process.

Data extraction

The following data was extracted from the included studies: year of publication; geographical origin; study design; method(s) of weight estimation studied or compared; sample size and the use of sample size calculations; sampling method; age-range of children included in the study; methodology and metrics used to report on bias, precision and accuracy; use of correlation and regression; use of the Bland & Altman method; and the use of subgroups in the study. Data was extracted by one author (DC) and independently confirmed by another (MW). Conflicting entries, disagreements and differences were resolved by consensus between the authors. The data was recorded in an electronic spreadsheet database in Microsoft Excel (Microsoft® Excel® for Microsoft 365).

Data analysis and grading of studies

This was primarily a descriptive review. A descriptive analysis was performed of the characteristics of the identified studies, the data reporting and the statistical methods used. An evaluation of the strength and reliability of the evidence from the studies in the review included an assessment of methodological and statistical flaws, using a modified Newcastle-Ottawa tool that has been used in previous systematic reviews on weight estimation (see ***Supplementary Table 1***) (3, 15-17). This tool is used to grade each study on risks of bias due to confounding, selection of participants, missing data, and measurement of the outcome. The impact of these risks on the validity of the overall study findings was also assessed. One of the factors that was considered to most impact the validity of the studies was the failure to include statistical analyses that provided a true measure of agreement of methods.

Outcomes

The main outcomes of interest were the quality of the studies, the appropriateness of the study design, the quality of the data analysis (including subgroup analysis) and the quality of the data reporting.

Ethics

Institutional Review Board (IRB) approval was not required as the data reviewed is public and the included articles had each received IRB approval previously.

RESULTS

General characteristics of included studies

A total of 193 articles were included in this review (see ***Supplementary Table 2***). *Figure* 1 contains an illustration of the selection process. The studies spanned over 32 years (1990-2022) and originated from across the globe. Most studies (78.8%) were prospective and single centre (68.4%). The Broselow tape was the paediatric weight estimation method most researched (59.1%). Only 37.8% of studies included a method of assessing body habitus. See ***Table 1*** for further details.

Table 1 General characteristics of the 193 studies included in the review.

Characteristic		Number of studies (%)
Year of publication	1980s	2 (1.0)
	1990s	10 (5.2)
	2000s	28 (14.5)
	2010s	120 (62.2)
	2020s	33 (17.1)
Region of origin of the studies	Africa	41 (21.2)
	Asia	41 (21.2)
	USA	40 (20.7)
	Europe	31 (16.1)
	Oceania	22 (11.4)
	Other regions	22 (11.4)
Study design	Prospective	152 (78.8)
	Retrospective	41 (21.2)
	Single centre studies	132 (68.4)
	Multi centre studies	61 (31.6)
Single/multiple methods studies	Single method only	83 (43.0)
	Multiple methods	110 (57.0)
Weight estimation methods studied	Broselow tape	114 (59.1)
	Age-based formulas	96 (49.7)
	PAWPER tape	31 (16.1)
	Parental estimations	20 (10.4)
	Mercy method	19 (9.8)
	Healthcare worker estimates	18 (9.3)
	Other Methods	61 (31.6)
Studies which included a method of assessing body habitus		73 (37.8)

Analysis of methodology

Among the population of included studies, reporting on many of the fundamental aspects of methodology was lacking (see ***Table 2***). Nearly half the studies did not report the study design clearly, sample size calculations were performed appropriately in one-third of studies, sampling methods were clearly stated in less than half of studies, and more than two-thirds of studies used convenience sampling. In addition, nearly three-quarters of studies had inclusion criteria which were at intermediate or high risk of introducing bias. The same was true for more than half the exclusion criteria.

Analysis of statistical analysis and data reporting

Only 98/193 (50.8%) of studies included appropriate metrics to show the bias of the studied methods, 106/193 (54.9%) reported appropriate methods for assessing precision, and 84/193 (43.5%) of studies used appropriate metrics to evaluate overall accuracy (see ***Table 3*** for full details). The Bland and Altman methodology was used with percentage error format in 58/193 (30.1%) of studies, and in 57/193 (29.5%) of studies it was used, but with residuals in kilograms.

Overall, only 64/193 (33.2%) of studies used complete and appropriate statistics and metrics that provided a comprehensive evaluation of the performance of the weight estimation system. A further 49/193 (25.4%) had appropriate, but incomplete, statistical reporting. However, 80/193 (41.5%) studies relied exclusively upon inappropriate metrics and statistics that did not adequately describe the performance of the weight estimation system. The most prevalent of the unsuitable methods for evaluating performance were Pearson’s correlation analysis in 72/193 (37.3%) studies, and intraclass correlation in 25/193 (13.0%) studies. The rate of inappropriate data reporting was consistently high in each decade since the first weight estimation studies: 1990s 4/10 studies (40%), 2000s 19/28 studies (67.9%), 2010s 47/120 studies (39.2%), 2020s 10/33 studies (30.3%).

Table 2-Methodological analysis of the included studies.

Characteristics		**Number of studies (%)**
Study design	Clearly stated	104 (53.9)
	Description inadequate or incomplete	65 (33.7)
	Poorly described	24 (12.2)
Sample size calculations	Performed appropriately	65 (33.7)
Sample size	≤300 participants	42 (21.8)
	301-500 participants	42 (21.8)
	501-1000 participants	40 (20.7)
	>1000 participants	68 (35.2)
Sampling methods	Clearly stated[1]	79 (40.9)
	Convenience	126 (65.3)
	Consecutive	20 (10.4)
	Systematic/random[2]	47 (24.4)
Maximum age of children enrolled	≤8 years	22 (11.4)
	12 years	84 (43.5)
	18 years	64 (32.5)
	>18 years	4 (2.0)
Minimum age of children enrolled	<1year	119 (61.7)
	1 year	51 (26.4)
	>1 year	23 (11.9)
Inclusion criteria	Clearly stated	163 (84.5)
	Limited to length limits of Broselow tape	10 (6.1)
	Limited to specific age	103 (63.2)
	Low risk for bias[3]	45 (27.6)
Exclusion criteria	Clearly stated	152 (78.8)
	Limited to length limits of Broselow tape	39 (25.7)
	Limited to specific age	5 (3.3)
	Medical conditions affecting weight	34 (22.4)
	Low risk for bias[4]	65 (42.8)

[1]The sampling method had to be inferred from the study description if it was not clearly described.
[2]The term systematic sampling was used for retrospective studies on existing datasets in which all participants were included.
[3,4] Inclusion and exclusion criteria that were appropriate to ensure that the weight estimation system was evaluated in a wide range of children, and in a population typical of what might be seen in a paediatric emergency department.

Table 3-Statistical methodology used to assess bias, precision, and accuracy.			
	Statistical methods used	**Number of studies (%)**	**Analysis**
Bias	Mean percentage error / mean percentage difference	91 (47.2%)	Optimal
	Mean difference / mean error	70 (36.3%)	Sub-optimal
Precision	Mean absolute percentage error	55 (28.5%)	Optimal
	Root mean square percentage error	18 (9.3%)	
	95% limits of agreement	105 (54.4%)	
	Mean error / mean difference	70 (36.3%)	Sub-optimal
	Root mean square error	21 (10.9%)	
	Standard deviation	99 (51.3%)	
	Variance	26 (13.5%)	
Bland & Altman methodology	Not used	69 (35.8%)	
	Used with residuals in percentage format	58 (30.1%)	Optimal
	Used with residuals in logarithmic format	9 (4.7%)	Sub-optimal
	Used with residuals in kilograms	57 (29.5%)	Sub-optimal
Accuracy	P5	10 (5.2%)	Optimal
	P10	121 (62.7%)	
	P20	78 (40.4%)	
	P other	26 (13.5%)	

With respect to subgroup analyses, 137/193 (71.0%) presented no useful information on weight estimation performance in subgroups. Only 13 (6.7%) studies presented data for both age or weight categories as well as BMI categories, while 30/193 (32.3%) reported data for only age or only weight categories.

When assessing the risk of bias using the Newcastle-Ottawa tool a similar pattern emerged. Poor statistical methodology, including determination of and control for confounding factors, was common (see **Supplementary Figure 1** & **Supplementary Figure 2***)*

DISCUSSION

The primary objective of research studies focused on paediatric weight estimation systems is to determine the most suitable and accurate method to use. For clinicians and researchers reading these studies, their requirement is to be able identify which method is most appropriate for use in their patient population. To be able to draw reliable conclusions, the studies must be well designed with transparent methodology, as well as robust and comprehensive data reporting and data analysis. However, some authors have raised concerns that many weight estimation studies are not well conducted, and that the data reporting and analysis may be incomplete, improper, or incorrect (18). The extent of the problem has not been clear. The importance of this study was in determining the prevalence of high- and low-quality weight estimation studies, as well as the potential need for guidelines to ensure that published articles are of a suitable standard to allow clinicians to make rational decisions based on their findings.

The major findings in this study were that poor sampling methods, poor inclusion/exclusion criteria, poor statistical analysis, poor data reporting, and inadequate use of subgroup analyses frequently impacted the overall findings of the studies. These peer reviewed articles were published in mainstream journals, but major methodological flaws and limitations were unrecognized. The rate of inappropriate data reporting has been consistently high in each decade since the first weight estimation studies and irrespective of the weight estimation method being investigated. Thus, despite an increased focus on the practice of evidence-based medicine, there has been no significant improvement in the quality of published studies in this field. The publication of studies with inappropriate metrics, statistics, and data reporting conflicts with a culture of evidence-based medicine.

Concerns about study designs

The methodology was poorly described (and possibly executed) in many of the reviewed studies. Appropriate sampling strategies and inclusion and exclusion criteria form some of the fundamental components when undertaking research. These errors in the methodology can introduce bias and negatively affect the reproducibility and generalizability of the study. Convenience sampling (in two-thirds of studies) and small sample sizes (nearly half the studies had fewer than 300 participants) introduced the potential for significant bias. In addition, only a third of the studies utilised sample size calculations. Underpowered samples may generate misleading results.

The inclusion and exclusion criteria used in many of the studies were problematic as they introduced a substantial risk of bias, limiting the validity and generalizability of the findings. For example, approximately a third of the studies limited the sample population based on the length parameters of the Broselow tape. This is inappropriate as the number of patients who could not be assessed by the tape is also of value to the reader. This would highlight the percentage of patients which wouldn't benefit from the system. The bias introduced by excluding children "too tall for the tape" has been comprehensively described. The same principle applies to limitations based on age. Inclusion and exclusion criteria should, ideally, accurately reflect the patient population normally seen in the study environment.

The *ideal study* should make use of consecutive or random sampling, with a sufficient sample size for appropriate subgroup analyses. The sample population should closely resemble the patient population in which the weight estimation system would be used, with broad inclusion criteria and very limited exclusion criteria. These criteria should specifically not exclude participants based on the limitations of the weight estimation system.

Concerns about statistical analyses and data reporting

Paediatric weight estimation studies are typical method comparison studies: an estimated weight is compared against a measured weight. Therefore, the correct metrics for bias, precision, and accuracy (see ***Table 4***) need to be included in the methodology to ensure that the performance of the estimation method is appropriately evaluated and reported (19). In this review, we found that nearly half of the identified paediatric weight estimation studies relied exclusively upon inappropriate metrics and statistics (mostly forms of correlation analysis, or measures of bias or precision used alone). This improper use of statistical methods is a matter of significant concern that should not be ignored. Unfortunately, only one-third of studies used complete and appropriate metrics and statistics, with an additional one-quarter using appropriate, but incomplete statistical reporting. The significance of this is that there are few methodologically valid and reliable studies from which to draw evidence to guide practice.

While there have been no previous reviews evaluating weight estimation studies, reviews in other fields have found a high proportion of studies with incomplete or sub-optimal “sample selection, study design and statistical analysis” (Zaki *et al)* (20-22). This is a significant problem in medical science. If clinicians and medical researchers alike are unable to recognise this problem, the use of incorrect statistical analyses may result in misguided conclusions and the quality of care provided to patients may then be negatively affected. Proper statistical analysis helps ensure that weight estimation methods are both precise and reliable, minimizing the potential for errors and enhancing the safety of medical interventions. Furthermore, these studies often involve data from diverse paediatric populations, making appropriate statistical techniques essential to account for variations and to provide more inclusive and effective solutions. In a field as sensitive as paediatric emergency care, the correct statistical analysis serves as a crucial foundation for evidence-based, patient-centred care.

The ideal analysis would begin with an adequate description of the study sample, especially in terms of ages of participants, and the distribution of participants in different weight classes. The statistical analysis would be based on percentage errors, and include mean percentage error (bias), 95% limits of agreements (precision), mean absolute percentage error (precision) and percentages of estimates within 10% and 20% of actual weight (accuracy)(17, 23, 24). Subgroup analyses would be essential (see below).

<table>
<tr><th colspan="2">Table 4-Examples of how statistical analyses were inappropriately applied and interpreted to assess the performance of weight estimation systems.</th></tr>
<tr><th>Critical error</th><th>Description of the problem</th></tr>
<tr><td>Correlation used to show accuracy</td><td>Pearson’s correlation is a statistical method commonly misused in weight estimation studies to measure agreement between actual and estimated weight. However, a good correlation does not necessarily imply agreement between measured and estimated weight (see example below). Therefore, the correlation coefficient is a deficient representation of agreement. Some authors have extended the correlation analysis to regression analysis, where the coefficient of determination (r^2) serves as an agreement metric, but its reliability is compromised as it hinges on a mathematical concept akin to the correlation coefficient. It showcases the proportion of variation in the dependent variable that is explained by the regression model instead of representing agreement (20). The closer the points in the scatter diagram are dispersed around the regression line, the higher the proportion of variation explained by the regression line and hence the higher the value of r^2(20). Unless the slope of the line is very close to 1, with a high r^2, the agreement may not be good at all.

Example:
<table>
<tr><th>Patient</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th></tr>
<tr><td>Actual weight (kg)</td><td>12</td><td>14</td><td>16</td><td>18</td><td>20</td><td>22</td><td>24</td></tr>
<tr><td>Method A (kg)</td><td>10</td><td>12</td><td>14</td><td>16</td><td>18</td><td>20</td><td>22</td></tr>
<tr><td>Method B (kg)</td><td>20</td><td>24</td><td>28</td><td>32</td><td>36</td><td>40</td><td>44</td></tr>
</table></td></tr>
<tr><td>Intraclass correlation used to show accuracy</td><td>Originally designed to measure reliability, the ICC was later adopted to assess agreement because of the concerns that linear relationships will be misinterpreted as agreement using Pearson’s correlation. To overcome the constraints of the correlation coefficient (r), the Intraclass Correlation Coefficient (ICC) computes the average of correlations across all conceivable pair orderings(20). In contrast to most other measures of correlation, ICC analyses data in groups, rather than paired observations. Additionally, the ICC treats both methods as random samples from a population of methods, ignoring the fact that in an agreement study, specific methods are being compared. Another drawback of the ICC, and perhaps the most important, is that it is powerfully influenced by the range of data. When there is substantial variance among subjects, the ICC value will seem elevated(20). In a sample in which some children weigh 10kg and others weigh 50kg (or higher), this bias is always present. Even the correct method of using ICC in this setting is debated. Therefore, while widely used, the appropriateness of the ICC for assessing agreement is controversial. Bland and Altman have also condemned the use of ICC to assess agreement (25): not only is it inherently statistically biased, but other, better, methods of assessing agreement are available.</td></tr>
<tr><td>Correlation used for comparison between weight estimation systems</td><td>Since Pearson’s correlation and intraclass correlation do not show agreement between methods, and do not accurately portray the accuracy of a weight estimation method, it follows that these methods cannot be used to compare weight estimation methods. Neither similar nor different correlations provide any useful information.</td></tr>
<tr><td>Comparison of means</td><td>The paired t-test has also been misused by researchers for comparisons between means of actual weights and estimated weight, or two different methods of weight estimation. However, it is incorrect to assume that non-significant results indicate agreement (or accuracy), as the value of the mean is influenced by each individual data point, including outliers. Therefore, it is possible for two methods of weight measurement or estimation to have poor agreement but still appear to agree based on the distribution of differences. In an agreement study, the focus should be on the individual readings, not the means obtained from each method(20). The importance of the findings is linked to the study’s statistical power. These types of statistical tests essentially only evaluate the bias of weight estimation systems, and not the precision or overall accuracy.</td></tr>
</table>

<table>
<tr><td>Bland-Altman analysis in kg format</td><td>The Bland-Altman analysis is a statistical method used to assess agreement between two different methods of measurement. In the context of paediatric weight estimation studies, it is commonly used to compare the performance of different methods of estimating a child's weight. When using the Bland-Altman analysis, it is important to express the measurement differences in a way that is proportional to the size of the measurements being compared. This is because differences that are small in absolute terms may be significant in proportion to the size of the measurements. In the case of paediatric weight estimation studies, using kilograms (kg) rather than percentages (%), can be problematic because the magnitude of the measurement differences in kg can be much larger than the magnitude of the differences expressed as a percentage. For example, a weight estimation method has a mean difference of 1 kg when compared to actual weight, this may seem like a small difference in absolute terms. However, if the weight of the child being measured is only 10 kg, then this represents a 10% difference in weight estimation, which may be clinically important. Expressed in a different way, a 5 kg error of estimation is negligible in a 50 kg child, but potentially critical in a 10 kg child. Here, errors expressed as 10% and 50%, respectively, have much more meaning. Thus, if the difference is expressed as a percentage, such as a 10% difference, then it is proportional to the size of the measurement and can be easily interpreted in the context of the study. Therefore, it is generally recommended to use percentages (%), rather than kilograms (kg), in Bland-Altman analysis for paediatric weight estimation studies to ensure that the measurement differences are proportional to the size of the measurements being compared.</td></tr>
<tr><td>Measures of bias used alone</td><td>The use of mean percentage error (%) or mean error (kg) alone to describe or compare the performance of weight estimation systems is not appropriate. These metrics provide a measure of the bias of the estimation system with no further information. Two systems may have an identical bias (see example below) but substantially different precision and overall accuracy. Therefore, while a measure of bias is useful to understand the overall performance of a weight estimation system, it is powerless on its own to describe agreements between weight estimation methods.
e.g., the percentage error of estimates in seven children examined with two weight estimation methods are shown here:
<table>
<tr><th>Patient</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>G</th></tr>
<tr><td>Method A (% error)</td><td>0</td><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td><td>12</td></tr>
<tr><td>Method B (% error)</td><td>-6</td><td>-2</td><td>2</td><td>6</td><td>10</td><td>14</td><td>18</td></tr>
</table>
Both Method A and Method B have a mean percentage error of 6%, but the accuracy of Method B is clearly inferior to that of Method A. It is clear that this metric does not provide sufficient information to quantify the performance of a weight estimation system, nor to compare different weight estimation systems.</td></tr>
<tr><td>Subgroup analyses</td><td>The three patient factors that are most important in determining the accuracy of a weight estimation system are age, total body weight (which is collinear with age), and body habitus (represented by BMI-for-age centiles, z-score, or other metrics). Any study that does not evaluate the performance of a weight estimation system in subgroups of age/weight and BMI may present biased findings. The composition of the sample might significantly influence the outcomes of the analyses: a sample with few older or few obese children will falsely flatter most weight estimation systems. These analyses are therefore important to show how generalizable a weight estimation system may be, or what its weaknesses might be.</td></tr>
<tr><td>Inappropriate inclusion and exclusion criteria</td><td>The exclusion, or failure to include, any group of children who might require a weight estimation in a clinical environment, could lead to significant bias in the study findings. Many studies in this review had exclusions related to length (if the Broselow tape was studied) or age (if age formulas were studied). While this might test the performance of these methods within their limitations, it is illustrative of a biased sampling methodology. The questions remain: what about children too tall for the Broselow tape, or children too old for the age-based formulas? The real-world performance of these methods cannot be accurately inferred from these studies. These methodological weaknesses should be avoided in weight estimation studies with more appropriate sampling methods, such as consecutive or random sampling.</td></tr>
</table>

Concerns about lack of subgroup analyses

Almost invariably, weight estimation systems perform best in a prepubertal, average-sized, normal weight child. Similarly, most weight estimation systems perform worst in older children, underweight and obese children. Therefore, the composition of the study sample, in terms of age and weight status, will have an important effect on the evaluation of the performance of a weight estimation system. For example, the Broselow tape will appear very accurate in a sample of young, normal weight children, but far less accurate in a sample of older children with a higher prevalence of underweight or obese children (26-28). For this reason, it is essential to report these sample characteristics and perform subgroup analyses by age and weight status to provide context for the performance data. It is important to highlight that most of the studies in this review presented no useful information on weight estimation in subgroups. This reveals a major flaw in these studies. It also limits the generalizability of the findings. If the bias, precision, and accuracy of a method are not tested in the subgroups which most determine weight estimation accuracy, the clinician cannot make an informed decision regarding its application to their patient population. With fewer than a tenth of studies presenting data for both appropriate age categories as well as weight status categories, it is likely that valuable conclusions cannot be derived from much of the available literature.

The ideal subgroup analyses would include analyses by weight status and by age. This should be conducted in any evaluation of the performance of a weight estimation system.

Guidelines for weight estimation studies

An additional important factor to consider is that published articles can be utilised as templates for further research. Thus, errors in these papers may lead to the mistakes and inappropriate use of metrics and statistical analyses being perpetuated in future research. To avoid this, guidelines for the methodology to be used in paediatric weight estimation studies or research should be developed for researchers and reviewers alike. This is essential for the development of appropriate evidence to guide emergency medical care.

Limitations

This study has potential limitations. The major limitation in this research is that some studies may not have been identified through the search strategy. The literature search was limited to four major electronic databases and limited to articles published in English (or with a translation). The search was only performed using online databases, and unpublished articles or data may not have been identified. This may have limited the generalizability of the study because of selection bias. However, these databases have an extensive coverage of published medical journals including the grey literature. We sought to mitigate bias by using two independent reviewers throughout the processes of identification, selection, and data extraction.

Future directions

Given the high prevalence of poorly conducted studies, appropriate guidelines should be established for the methodology, statistical analysis, and data reporting of weight estimation studies. These could be created by experts in this field and adopted by journal editors and reviewers to increase the quality of paediatric weight estimation studies.

Conclusions

This is the first study to evaluate the methodology and data analysis of published paediatric weight estimation studies. We identified major limitations in study design, methodology and data analysis in many studies. The most important limitations were sub-optimal sampling and inclusion/exclusion criteria and the failure to use appropriate statistical and subgroup analyses. The fact that only one third of studies presented complete and appropriate data was of concern and reflects a major impact on this field of study. Clinicians, researchers, journal editors, and reviewers need to be aware of this and put measures in place to ensure only studies with sound methodologies and supportable conclusions are published.

APPENDIX A: Supplementary Tables

Supplementary Table 1-Newcastle-Ottawa Scale

The Newcastle-Ottawa Scale adapted for weight estimation accuracy studies. Evaluated studies were downgraded if there were significant methodological weaknesses, or if data presentation was incomplete, or if performance outcome data was not appropriately presented or analyzed.
Selection: (Maximum 5 stars) 1. Representativeness of the study sample: a. Truly representative of the target population (all subjects or random sampling) ★★★ b. Somewhat representative of the target population (non-random sampling) ★★ c. Selected group. d. No description of the sampling strategy. 2. Sample size: a. Justified and acceptable ★ b. Not justified. 3. Prospective data ★ 4. Appropriate application of weight estimation technique ★
Comparability of cohorts based on the design or analysis: (Maximum 2 stars) 1. Paired data ★★ 2. Study controls adequately for additional factors ★
Outcome: (Maximum 3 stars) 1. Assessment of the outcome: a. Independent blinded assessment ★★ b. Independent non-blinded assessment ★ c. Non-blinded assessment ★ d. No description If data analysis was not appropriate for method-comparison studies (no assessment of bias, precision (or repeatability if applicable) and accuracy) then consider downgrading one level. 2. Statistical test: a. Appropriate, clearly described statistical analysis with confidence intervals or measure of variance ★ b. The statistical test is not appropriate, not described, or incomplete. If study did not group ages / weight categories appropriately or alternatively use percentage error analysis or logarithmic transformation, then downgrade to ‘b’.

Supplementary Table 2-All studies included in the systematic Review

Author	Year	Country	Sample Size	Design	Sampling	Age range (years)	Methods studied
Garland *et al* (29)	1986	USA	258	Single centre prospective observational study	Convenience	1-15	Age-based formulas, DWEM
Lubitz *et al* (30)	1988	USA	937	Multi centre prospective observational study	Convenience	0-11	Age-based formulas, Broselow tape, DWEM
Hughes *et al* (31)	1990	England	163	Single centre prospective observational study	Consecutive	0-10	Broselow tape, Healthcare provider estimates
Haftel *et al* (32)	1990	USA	100	Single centre prospective observational study	Convenience	0-15	Hanging leg weight
Davis *et al* (33)	1994	USA	1693	Multi centre retrospective database review study	Systematic	0-11	Parental estimates
Rajeev *et al* (34)	1996	India	204	Single centre retrospective observational study	Convenience	0-5	RJ Index
Greig *et al* (35)	1997	England	75	Single centre retrospective observational study	Convenience	0-12	Healthcare provider estimates
Leffler *et al* (36)	1997	USA	117	Single centre prospective observational study	Convenience	0-5	Age-based formulas, Parental estimates
Dearlove *et al* (37)	1999	England	50	Single centre prospective observational study	Convenience	1-16	Age-based formulas, Broselow tape, Parental estimates
Goldman *et al* (38)	1999	Israel	233	Single centre prospective descriptive study	Convenience	NR	Parental estimates
Harris *et al* (39)	1999	USA	100	Single centre prospective observational study	Convenience	0-8	Parental estimates, Healthcare provider estimates
Molyneux *et al* (40)	1999	Malawi	729	Single centre prospective observational study	Convenience	NR	Healthcare provider estimates, Blantyre tape
Kun *et al* (41)	2000	China	909	Single centre prospective observational study	Convenience	0-12	Broselow tape
Vilke *et al* (42)	2001	USA	20	Single centre prospective observational study	Random	1-19	Broselow tape, Healthcare provider estimates
Uesugi *et al* (43)	2002	Japan	48	Single centre prospective observational study	Convenience	NR	Healthcare provider estimates, other
Hofer *et al* (44)	2002	Switzerland	585	Single centre retrospective chart review study	Systematic	0-11	Broselow tape
Black *et al* (45)	2002	Australia	495	Single centre prospective observational study	Convenience	0-18	Age-based formulas, Broselow tape, DWEM, other
Argall *et al* (46)	2003	England	300	Single centre prospective observational study	Convenience	1-10	Age-based formulas, Broselow tape
Bavdekar *et al* (47)	2005	India	500	Single centre prospective observational study	Consecutive	0-2	DWEM
Theron *et al* (48)	2005	New Zealand	909	Single centre prospective observational study	Consecutive	0-10	Age-based formulas, Broselow tape, other
Menon *et al* (49)	2005	Australia	1137	Single centre prospective observational study	Convenience	0-16	Healthcare provider estimates, other
Varghese *et al* (50)	2006	India	500	Single centre prospective cross-sectional study	Systematic	0-12	Broselow tape
Nieman *et al* (51)	2006	USA	7813	Multi centre prospective observational study	Systematic	0-12	Broselow tape
Luscombe *et al* (52)	2007	England	17244	Single centre retrospective observational study	Systematic	1-10	Age-based formulas

Tinning *et al* (53)	2007	Australia	67363	Single centre retrospective observational study	Systematic	0-15	Age-based formulas
DuBois *et al* (54)	2007	USA	400	Single centre prospective observational study	Convenience	0-19	Broselow tape, DWEM
Hashikawa *et al* (55)	2007	USA	1207	Multi centre retrospective observational study	Random	0-12	Broselow tape
Nguyen *et al* (56)	2007	Australia	410	Single centre prospective observational study	Convenience	1-11	Age-based formulas
Jang *et al* (57)	2007	South Korea	665	Single centre retrospective chart review study	systematic*	0-12	Broselow tape
Kelly *et al* (58)	2007	Australia	410	Single centre secondary analysis study	Convenience	1-11	Age-based formulas
Krieser *et al* (59)	2007	Australia	410	Single centre prospective observational study	Convenience	1-11	Age-based formulas, Broselow tape, Parental estimates
Thompson *et al* (60)	2007	Australia	1843	Single centre retrospective observational study	Convenience	0-15	Age-based formulas
Zink *et al* (61)	2008	USA	127	Single centre prospective observational study	Convenience	0-17	Broselow tape, DWEM, Parental estimates, Healthcare provider estimates
Grivas *et al* (62)	2008	Greece	5093	Multi centre prospective observational study	Convenience	4-18	Other
Ramarajan *et al* (63)	2008	India	548	Single centre prospective observational study	Convenience	0-12	Broselow tape
So *et al* (64)	2009	USA	1011	Single centre prospective observational study	Consecutive	0-10	Age-based formulas, Broselow tape
Partridge *et al* (65)	2009	USA	812	Single centre prospective observational study	Convenience	0-20	Parental estimates, Healthcare provider estimates
Sandell *et al* (66)	2009	England	544	Single centre prospective observational study	Consecutive	0-11	Age-based formulas, other
Yamamoto *et al* (67)	2009	USA	542	Single centre prospective observational study	Convenience	NR	Broselow tape, other
Stewart *et al* (24)	2009	Australia	475	Multi centre prospective observational study	Convenience	0-10	Broselow tape
Casey *et al* (68)	2010	Australia	1235	Single centre prospective observational study	Convenience	0-14	Age-based formulas, Broselow tape
Williams *et al* (69)	2010	Australia	1400	Multi centre prospective observational study	Random	0-8	Healthcare provider estimates
Cattermole *et al* (70)	2010	China	1370	Multi centre prospective observational study	Convenience	1-11	Age-based formulas, Broselow tape, other
Knight *et al* (71)	2011	USA	657	Single centre retrospective chart review	Systematic	0-16	Broselow tape
Luscombe *et al* (72)	2011	England	94229	Single centre retrospective observational study	Systematic	1-14	Age-based formulas
Kelly *et al* (73)	2011	Australia	410	Single centre secondary analysis study	Convenience	1-11	Age-based formulas
Bourdeau *et al* (74)	2011	Canada	243	Multi centre retrospective chart review study	Systematic	0-10	Broselow tape
Geduld *et al* (75)	2011	South Africa	2832	Single centre retrospective chart review study	Consecutive	1-10	Age-based formulas, Broselow tape
Rosenberg *et al* (76)	2011	USA	372	Single centre prospective observational study	Convenience	0-14	Broselow tape, Healthcare provider estimates, other
Cattermole *et al* (77)	2011	China	1248	Multi centre prospective observational study	Convenience	1-10	Age-based formulas
Elgie *et al* (78)	2012	England	188	Single centre prospective observational study	Convenience	0-10	Age-based formulas
Heyming *et al* (79)	2012	USA	572	Single centre prospective observational study	Consecutive	1-4	Broselow tape

Seddon *et al* (80)	2012	England	599	Single centre prospective study	Consecutive	0-12	Age-based formulas
Milne *et al* (81)	2012	Canada	6361	Multi centre prospective observational study	Systematic	0-18	Broselow tape
Park *et al* (82)	2012	South Korea	124094	Multi centre prospective study	Random	0-14	Age-based formulas, Broselow tape
Trakulsrichai *et al* (83)	2012	Thailand	595	Single centre prospective observational study	Convenience	0-12	Broselow tape, Parental estimates, other
Ali *et al* (84)	2012	West Indies	1723	Single centre retrospective observational study	Consecutive	1-5	Age-based formulas
Abdel-Rahman *et al* (85)	2012	USA	19266	Multi centre prospective observational study	Random	0-16	Broselow tape, Mercy method, other
Sinha *et al* (86)	2012	USA	118	Single centre prospective observational study	Consecutive	0-14	Broselow tape
House *et al* (87)	2013	Kenya	967	Single centre prospective observational study	Convenience	0-14	Age-based formulas, Broselow tape
Lim *et al* (88)	2013	USA	199	Single centre retrospective chart review study	Systematic	0-17	Healthcare provider estimates
Abdel-Rahman *et al* (89)	2013	USA	976	Single centre prospective observational study	Convenience	0-16	Age-based formulas, Broselow tape, Mercy method
Abdel-Rahman *et al* (90)	2013	USA	624	Multi centre prospective observational study	Convenience	0-16	Broselow tape, Mercy method
Hegazy *et al* (91)	2013	Egypt	508	Single centre prospective observational study	Convenience	1-16	Age-based formulas
Loo *et al* (92)	2013	Singapore	875	Single centre prospective observational study	Convenience	1-10	Age-based formulas, Broselow tape
Wells *et al* (93)	2013	South Africa	453	Multi centre prospective observational study	Convenience	0-12	Broselow tape, PAWPER tape
Eke *et al* (94)	2014	Nigeria	370	Single centre prospective observational study	Convenience	1-12	Age-based formulas
Erker *et al* (95)	2014	Germany		Multi centre prospective observational study	Convenience	1-12	Age-based formulas
Flannigan *et al* (96)	2014	Ireland	10081	Multi centre retrospective chart review study	Systematic	0-15	Age-based formulas
Graves *et al* (97)	2014	Australia	37114	Single centre retrospective database study	Systematic	0-14	Age-based formulas, Broselow tape
Dicko *et al* (98)	2014	Mali	473	Single centre prospective observational study	Convenience	0-16	Age-based formulas, Broselow tape, Mercy method
Omisanjo *et al* (99)	2014	Nigeria	2754	Multi centre prospective observational study	Random	0-11	Age-based formulas
Young *et al* (100)	2014	USA	207	Single centre prospective observational study	Convenience	1-9	Age-based formulas, Broselow tape, Parental estimates, other
Huang *et al* (101)	2014	USA	39	Single centre prospective observational study	Convenience	6-18	Age-based formulas, other
Ackwerh *et al* (102)	2014	USA	13933	Single centre retrospective database study	Random	2-12	Age-based formulas
Aliyu *et al* (103)	2014	Nigeria	409	Single centre prospective observational study	Random	0-5	Other
Allison *et al* (104)	2014	Australia	2102	Multi centre retrospective chart review study	Random	0-5	Age-based formulas, Broselow tape, O
Britnell *et al* (105)	2014	New Zealand	376	Multi centre prospective observational study	Random	5-10	Age-based formulas, Broselow tape
Cattermole *et al* (106)	2014	China	782	Multi centre chart review study	Convenience	7-11	Other
Chiengkriwate *et al* (107)	2014	Thailand	3869	Single centre retrospective database study	Convenience	0-15	Broselow tape

Udoh *et al* (108)	2015	Nigeria	114	Single centre prospective observational study	Convenience	1-14	Age-based formulas
Young *et al* (109)	2015	Philippines	207	Multi centre prospective cross sectional study	Convenience	1-9	Age-based formulas, Broselow tape, other
Pattanarattanamolee *et al* (110)	2015	Thailand	630	Single centre prospective observational survey	Random	0-12	Broselow tape
Asskaryar *et al* (111)	2015	India	1185	Single centre prospective observational study	Convenience	0-12	Broselow tape, other
Badeli *et al* (112)	2015	Iran	216	Single centre prospective observational study	Convenience	1-10	Age-based formulas, DWEM, Parental estimates, Healthcare provider estimates
Chavez *et al* (113)	2015	USA	324	Single centre prospective observational study	Convenience	0-12	Age-based formulas, Broselow tape, PAWPER tape
Skrobo *et al* (114)	2015	Ireland	3155	Single centre retrospective chart review study	Systematic	1-15	Age-based formulas
Talib *et al* (115)	2015	USA	318	Single centre prospective observational study	Convenience	0-18	Age-based formulas, Broselow tape, Mercy method
Britnell *et al* (116)	2015	New Zealand	376	Multi centre prospective observational study	Convenience	5-10	Age-based formulas, Broselow tape
Garcia *et al* (117)	2015	USA	1698	Single centre prospective observational study	Convenience	0-12	PAWPER tape
Khouli *et al* (118)	2015	Mexico	815	Single centre prospective observational study	Convenience	0-12	Broselow tape
Abdel-Rahman *et al* (119)	2015	USA	80	Multi centre prospective observational study	Convenience	0-16	Age-based formulas, Broselow tape, Mercy method, DWEM, Healthcare provider estimates
Batmanabane *et al* (120)	2015	India	375	Single centre prospective observational study	Convenience	0-16	Age-based formulas, Broselow tape
AlHarbi *et al* (121)	2016	Saudi Arabia	3537	Multi centre prospective observational study	Convenience	0-11	Broselow tape
Chassee *et al* (122)	2016	USA	145	Single centre prospective observational study	Convenience	0-12	Broselow tape, Parental estimates, Healthcare provider estimates
Mishra *et al* (123)	2016	India	603	Single centre prospective observational study	Convenience	0-13	Broselow tape
Sahar *et al* (124)	2016	Malaysia	1163	Single centre prospective observational study	Convenience	0-12	Broselow tape
Aliyu *et al* (125)	2016	Nigeria	300	Single centre prospective observational study	Random	0-5	Age-based formulas, Broselow tape
Britnell *et al* (126)	2016	New Zealand	376	Single centre prospective observational study	Convenience	5-10	Age-based formulas, Broselow tape
Clark *et al* (127)	2016	Sudan	583	Multi centre retrospective observational study	Convenience	1-5	Age-based formulas, Broselow tape
Nosaka *et al* (128)	2016	Japan	237	Single centre prospective observational study	Convenience	0-10	Age-based formulas, Broselow tape, Parental estimates
Lowe *et al* (129)	2016	USA	3018	Multi centre retrospective observational study	Systematic	0-14	Broselow tape

Georgoulas *et al* (130)	2016	South Africa	300	Single centre prospective observational study	Convenience	0-12	Age-based formulas, Broselow tape, PAWPER tape, Mercy method
Ralston *et al* (131)	2016	USA	453990	Multi centre database study	Systematic	1-6	Age-based formulas, Broselow tape
So *et al* (132)	2016	China	4178	Single centre retrospective chart review study	Consecutive	1-9	Age-based formulas
So *et al* (133)	2016	China	4600	Single centre retrospective chart review study	Consecutive	1-12	Age-based formulas
Alsulaibikh *et al* (134)	2017	Saudi Arabia	527	Single centre prospective observational study	Convenience	0-13	Broselow tape
Gultekingil-Keser *et al* (135)	2017	Turkey	438	Single centre prospective observational study	Convenience	0-12	Broselow tape, Parental estimates, Healthcare provider estimates
Waseem *et al* (136)	2017	USA	538	Single centre retrospective chart review study	Convenience	0-8	Broselow tape
Lizo Garcia *et al* (137)	2017	Philippines	360	Single centre prospective observational study	Convenience	1-12	Age-based formulas, Broselow tape
Nasr-Esfahani *et al* (138)	2017	Iran	1500	Multi centre prospective observational study	Random	0-2	Broselow tape, DWEM
Nosaka *et al* (139)	2017	Japan	39547	Multi centre retrospective database study	Random	1-13	Age-based formulas
Tanner *et al* (140)	2017	USA	178	Single centre prospective observational study	Convenience	2-18	Broselow tape
Trainarongsakul *et al* (141)	2017	Thailand	345	Single centre prospective observational study	Consecutive	0-15	RAMA PED CARD
Papagiannopoulou *et al* (142)	2017	Greece	353	Single centre prospective observational study	Consecutive	2-12	Age-based formulas
Wetzel *et al* (143)	2017	Switzerland	627	Single centre prospective observational study	Convenience	0-13	Parental estimates, Healthcare provider estimates
Shah *et al* (144)	2017	India	356	Single centre prospective observational study	Convenience	1-12	Age-based formulas, Broselow tape
Wells *et al* (145)	2017	South Africa	332	Single centre prospective observational study	Convenience	0-16	PAWPER XL tape, Broselow tape
Abdel-Rahman *et al* (146)	2017	USA	2097	Multi centre prospective observational study	Convenience	0-0.25	Mercy method
Al-Busaidi *et al* (147)	2017	Oman	3339	Single centre retrospective chart review study	Systematic	3-9	Broselow tape
Both *et al* (148)	2017	Switzerland	3307	Single centre retrospective chart review study	Systematic	0-16	Broselow tape, Paed-ER tape
Both *et al* (149)	2017	Switzerland	489	Single centre prospective observational study	Convenience	0-6	Paed-ER tape
Jung *et al* (150)	2017	South Korea	906	Single centre prospective observational study	Convenience	0-16	Broselow tape
O'Leary *et al* (151)	2017	Australia	199	Single centre prospective observational study	Convenience	0-14	Age-based formulas, Broselow tape, PAWPER tape, Mercy method
Whitfield *et al* (152)	2017	Botswana	800	Single centre prospective observational study	Convenience	2-12	Broselow tape
Bowen *et al* (153)	2017	Zambia	1381	Single centre prospective observational study	Convenience	0-14	Age-based formulas, Broselow tape
McVey *et al* (154)	2017	Scotland	2086	Single centre prospective observational study	Random	0-18	Age-based formulas

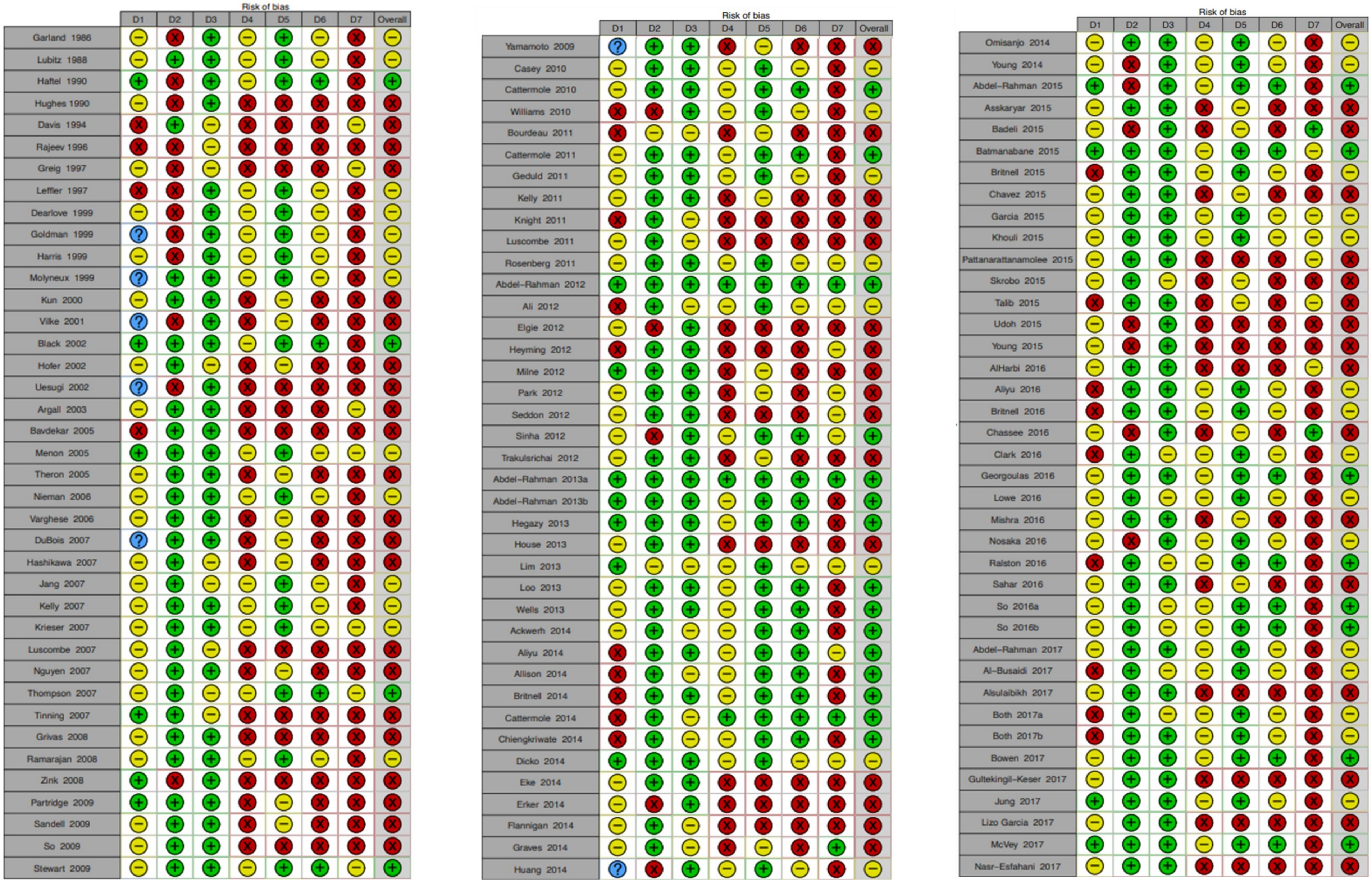
Wells *et al* (155)	2017	South Africa	332	Single centre prospective observational study	Convenience	0-16	Broselow tape, PAWPER tape, PAWPER XL tape, Mercy method
Wells *et al* (1)	2017	South Africa	1085	Multi centre secondary analysis of pooled data	Convenience	0-16	Age-based formulas
Wells *et al* (156)	2017	South Africa	13766	Multi centre retrospective database study	Systematic	0-18	PAWPER XL-MAC tape
Samerchua *et al* (157)	2017	Thailand	430	Multi centre prospective observational study	Convenience	1-12	Age-based formulas, Broselow tape, Mercy method, Parental estimates
Larose *et al* (158)	2018	Canada	40	Single centre secondary analysis of data	Random	NR	Broselow tape
Appelbaum *et al* (159)	2018	England	1076743	Multi centre retrospective database study	Systematic	0-11	Age-based formulas
Ruiz Brunner *et al* (160)	2018	Argentina	861	Multi centre prospective observational study	Consecutive	2-18	MAC; KHH
Choi *et al* (161)	2018	Republic of Korea	91147	Multi centre retrospective chart review study	Convenience	1-11	Age-based formulas, Broselow tape
Schmidt *et al* (162)	2018	Switzerland	312	Single centre prospective observational study	Convenience	1-6	CLAWAR
Wells *et al* (163)	2018	South Africa	138	Single centre prospective observational study	Convenience	1-16	Broselow tape, PAWPER tape, PAWPER XL tape
Kumar *et al* (164)	2018	India	1099	Single centre prospective observational study	Convenience	0-12	Broselow tape
Ralston *et al* (165, 166)	2018	USA	1800322	Multi centre retrospective database study	Systematic	1-6	Broselow tape
Shrestha *et al* (167)	2018	Nepal	813	Single centre prospective observational study	Convenience	0-14	Broselow tape, PAWPER XL tape, Mercy method
Wells *et al* (168)	2018	South Africa	1085	Multi centre secondary analysis of pooled data	Convenience	0-18	Broselow tape, PAWPER tape, PAWPER XL tape, Mercy method
Wells *et al* (169)	2018	South Africa	1085	Multi centre prospective secondary analysis raw data of 3 observational investigations study	Convenience	0-16	Broselow tape
Zhu *et al* (170)	2018	USA	1473	Multi centre prospective observational study	Convenience	2-5	Age-based formulas
Appelbaum *et al* (171)	2018	England	1070743	Multi centre retrospective database study	Systematic	4-11	Age-based formulas
Manirafasha *et al* (172)	2018	Rwanda	327	Single centre retrospective chart review study	Random	1-10	Age-based formulas, Broselow tape
Wells *et al* (173)	2018	South Africa	32	Single centre prospective observational study	Convenience	1-16	Broselow tape, PAWPER tape, PAWPER XL tape, Mercy method
Booysen *et al* (174)	2018	South Africa	121	Multi centre prospective observational study	Convenience	1-5	Age-based formulas
Marlow *et al* (175)	2019	England	57	Single centre prospective observational study	Convenience	1-15	Age-based formulas
Mbanga *et al* (176)	2019	Cameroon	544	Multi centre prospective observational study	Convenience	0-12	Age-based formulas
Sharma *et al* (177)	2019	India	9167	Multi centre secondary analysis of pooled data	Systematic	1-5	Age-based formulas

Ballesteros-Pena *et al* (178)	2019	Spain	780	Multi centre prospective observational study	Convenience	0-10	Age-based formulas
Pan *et al* (179)	2019	Australia	961	Single centre prospective cohort study	Convenience	0-10	Age-based formulas
Britnell *et al* (180)	2019	New Zealand	23	Single centre prospective observational study	Convenience	1-14	Age-based formulas
Iloh *et al* (181)	2019	Nigeria	1456	Multi centre prospective observational study	Consecutive	1-12	Broselow tape
Park *et al* (182)	2019	Republic of Korea	480	Multi centre prospective observational study	Convenience	0-16	Broselow tape
Foster *et al* (183)	2019	Australia	450	Single centre prospective observational study	Convenience	0-11	Parental estimates
Manyoni *et al* (184)	2019	South Africa	200	Single centre prospective observational study	Convenience	0-16	Broselow tape, PAWPER XL tape
Wells *et al* (185)	2019	South Africa	1717172	Multi centre retrospective database study	Systematic	1-6	Broselow tape, PAWPER XL-MAC tape
Wells *et al* (186)	2019	South Africa	1385	Multi centre secondary analysis of pooled data	Convenience	0-16	Broselow tape, PAWPER tape
Srimahadthai *et al* (187)	2020	Thailand	290	Single centre prospective observational study	Random	1-14	Weight (Kg) = 0.436x (midarm circumference)+ 0.857x(age)+0.111x(height) -5.913
Cerqueira *et al* (188)	2020	Brazil	446	Single centre prospective observational study	Convenience	0-14	Age-based formulas, Broselow tape
Madhusudhan *et al* (189)	2020	India	1083	Single centre prospective descriptive study	Convenience	0-12	Broselow tape
Charlton *et al* (190)	2020	England	341	Single centre prospective observational study	Convenience	1-11	Page for age weight guidance
Czarnecki *et al* (191)	2020	USA	198	Single centre prospective observational study	Convenience	0-14	Broselow tape, O
Cattermole *et al* (192)	2020	Rwanda	616	Single centre prospective observational study	Convenience	1-16	Age-based formulas, Broselow tape, PAWPER XL tape, PAWPER XL-MAC tape, Mercy method, Parental estimates
Edelu *et al* (193)	2020	Nigeria	1456	Multicentre prospective observational study	Convenience	1-12	Age-based formulas
Ong *et al* (194)	2020	Philippines	220	Single centre prospective observational study	Convenience	0-10	Broselow tape, PAWPER XL-MAC tape
Wells *et al* (195)	2020	South Africa	332	Single centre prospective observational study	Convenience	0-16	Age-based formulas, Broselow tape, PAWPER XL tape, Mercy method
Wells *et al* (196)	2020	South Africa	13132	Multi centre retrospective database study	Convenience	5-13	Mercy method, PAWPER XL-MAC tape
Wells *et al* (197)	2020	South Africa	1026	Multi centre secondary analysis of pooled data	Convenience	0-18	Age-based formulas, PAWPER XL tape
Wu *et al* (198)	2020	South Africa	300	Single centre prospective observational study	Convenience	0-18	Broselow tape, PAWPER XL tape, PAWPER XL-MAC tape, Mercy method

Pukar *et al* (199)	2020	Nepal	315	Single centre prospective observational study	Convenience	0-14	Age-based formulas, Broselow tape
Chomayil *et al* (200)	2021	Bahrain	2250	Multi centre prospective observational study	Convenience	0-13	Broselow tape
Stachurski *et al* (201)	2021	Poland	1103	Single centre retrospective descriptive study	Systematic	0-17	Age-based formulas, Parental estimates
Ruiz Brunner *et al* (202)	2021	Argentina	381	Multi centre prospective observational study	Convenience	2-19	Weight calculator CP
Karaca *et al* (203)	2021	Turkey	1094	Single centre prospective observational study	Convenience	1-12	Age-based formulas
Oommen *et al* (204)	2021	Peru	1160	Multi centre retrospective chart review study	Convenience	6-18	Broselow tape
Wells *et al* (205)	2021	South Africa	148	Multi centre secondary analysis of pooled data	Convenience	0-13	PAWPER tape, PAWPER XL tape
Britnell *et al* (206)	2021	New Zealand	17401	Multi centre retrospective database study	Systematic	2-14	Age-based formulas
Igbokwe *et al* (207)	2021	Nigeria	1390	Multi centre prospective observational study	Consecutive	1-12	Age-based formulas
Phiri *et al* (208)	2021	Zambia	330	Single centre prospective observational study	consecutive	0-14	Age-based formulas, Broselow tape
Suh *et al* (209)	2021	South Korea	108128	Multi centre retrospective database study	Systematic	0-12	Broselow tape
Yakubu *et al* (210)	2021	Ghana	775	Single centre prospective observational study	Convenience	0-13	Age-based formulas, Broselow tape
Brestovacki Svitlica *et al* (211)	2021	Serbia	750	Single centre retrospective chart review study	Random	0-12	Broselow tape
Saeed *et al* (212)	2022	USA	301	Single centre prospective observational study	Convenience	0-8	Broselow tape
Ateeq *et al* (213)	2022	Pakistan	1059	Single centre prospective observational study	Convenience	1-12	Age-based formulas
Castor *et al* (214)	2022	Philippines	350	Single centre prospective observational study	Convenience	0-12	Age-based formulas, Broselow tape, Mercy method
Waltuch *et al* (215)	2022	USA	549	Multi centre prospective observational study	Convenience	0-12	Broselow tape
Zhu *et al* (216)	2022	China	442	Single centre prospective observational study	Consecutive	0-12	Age-based formulas, Broselow tape
Silvagni *et al* (217)	2022	Italy	2060	Single centre prospective observational study	Convenience	0-12	Age-based formulas, Broselow tape, PAWPER tape, Parental estimates
Yakubu *et al* (218)	2022	Ghana	840	Single centre prospective observational study	Convenience	0-14	Broselow tape, PAWPER XL tape, PAWPER XL-MAC tape, Mercy method
Choi *et al* (219)	2022	South Korea	792	Single centre prospective observational study	Convenience	0-12	Broselow tape, PAWPER XL tape

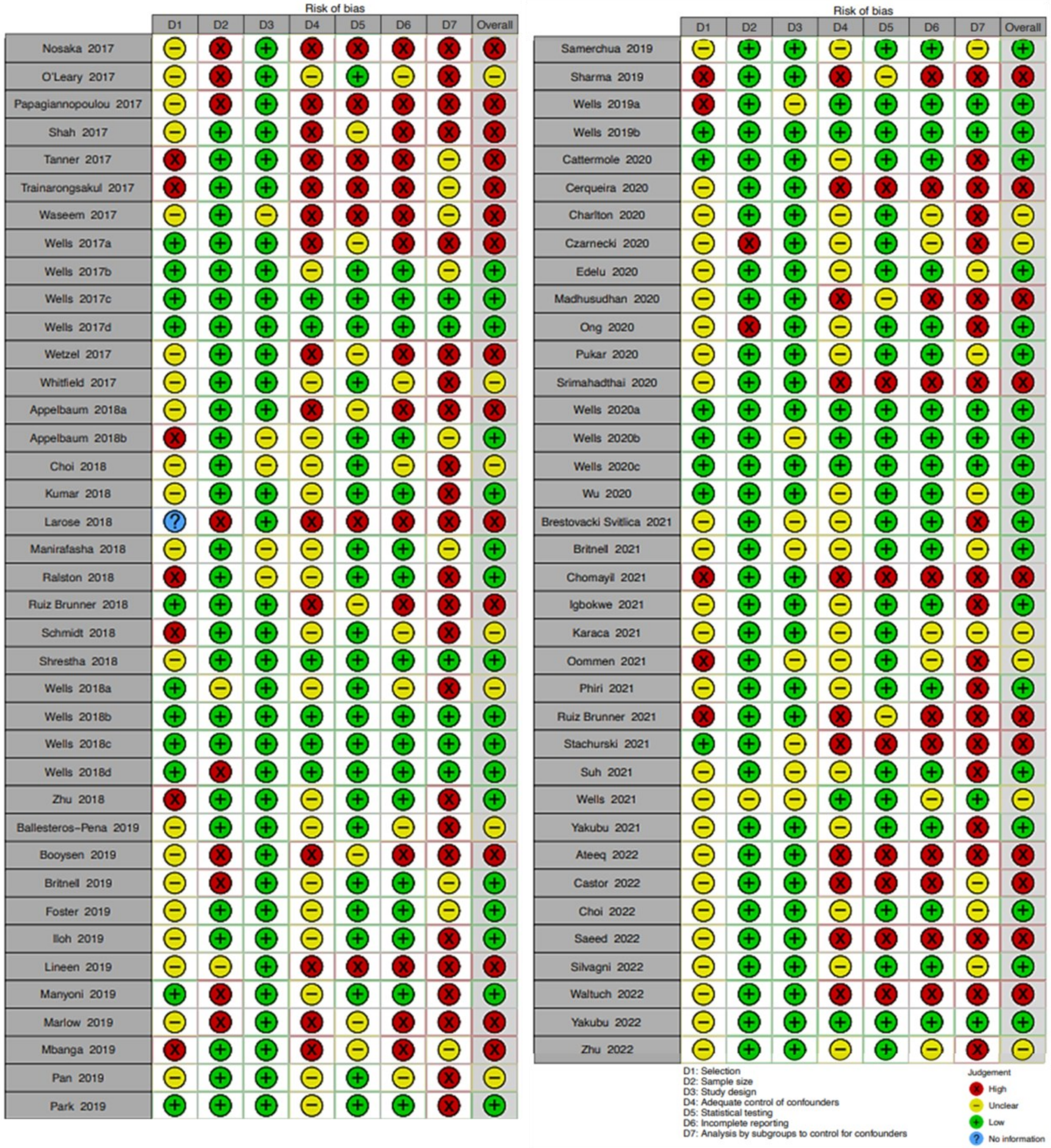
The term "Systematic" sampling was used for database studies or chart reviews in which all possible data points were included. Abbreviations: NR – not recorded.

APPENDIX B: Supplementary Figures

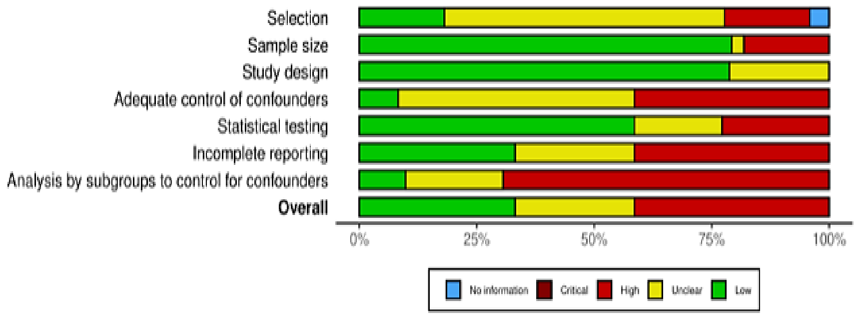


Supplementary Figure 1-Traffic light plot of the risk of bias assessment for the studies included in the review.

Supplementary Figure 1(cont)-Traffic light plot of the risk of bias assessment for the studies included in the review.



Supplementary Figure 2-Summary plot of the risk of bias assessment for the studies included in the review.



APPENDIX C- Ethics Clearance

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

21/02/2018

Ref: W-CBP-180221-01

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: Dr DS Carvalhal
Student No. (if appropriate): 07 0328 4V

Supervisor: Professor M Wells

School: Clinical Medicine
Department: Department of Emergency Medicine
Chris Hani Baragwanath Academic Hospital

Project title: *An analysis of the appropriateness of the statistical methodology and data reporting used in paediatric weight estimation studies - a systematic review*

Reason: Journal data analysis.
No human participants will be involved in the study.

CB Penny

Professor CB Penny
Chairperson: Human Research Ethics Committee (Medical)

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