Finger counting method is more accurate than age-based weight estimation formulae in estimating the weight of Hong Kong children presenting to the emergency department

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ABSTRACT

Objective

The aim of this study was to evaluate the finger counting method and compare its performance with four commonly used age-based weight estimation formulae in children aged 1-9 years presenting to the emergency department in Hong Kong.

Methods

A cross-sectional, observational study of children aged 1-9 who presented to the emergency department of a tertiary referral hospital in Hong Kong over a six-month period was conducted. Actual weight was compared with estimated weight using the finger counting method and four commonly used age-based weight estimation formulae. Bland-Altman analysis was performed to evaluate the degree of agreement in which the mean percentage difference (MPD) and 95% limits of agreement (LOA) were calculated. Root mean squared error (RMSE) and proportions of weight estimates within 10%, 15% and 20% of actual weight were determined.

Results

A total of 4178 children were included. The finger counting method was the most accurate method (MPD 0.1%; 95% LOA -34.0% to 34.2%). The original APLS formula (MPD -7.0%; 95% LOA -38.4% to 24.3%) and the updated APLS formula (MPD -0.4%; 95% LOA -38.5% to 37.8%) underestimated weight whereas the Luscombe formula (MPD 7.2%; LOA -31.8% to 46.2%) and the Best Guess formula (MPD 10.6%; 95% LOA -27.3% to 48.4%) overestimated weight. The finger counting method had smallest RMSE of 4.06 kg and estimated the largest proportion of children within 10%, 15% and 20% of actual weight.

Conclusion

The finger counting method outperforms the commonly used age-based weight estimation formulae in children aged 1-9 years presenting to the emergency

department in Hong Kong.

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Introduction

The knowledge of body weight is important in paediatric emergency as many of the interventions, such as drug dosages, fluid requirements, equipment sizes and settings, are based on the weight of the child. However, it is sometimes impractical to weigh the acutely unwell child on a calibrated scale before instituting any interventions. In the absence of an actual weight, a simple, rapid and accurate weight estimation method is essential in order to provide optimal care to the child in a time-critical manner.

The Advanced Paediatric Life Support (APLS) formula, the most well-known age-based weight estimation formula, has been widely taught and used in Australia, Europe, and South Africa.¹ However, as the weight of children in developed countries has increased in the past few decades, the APLS formula has been found to underestimate weight in recent studies conducted in Australia,²⁻⁴ Ireland,⁵ USA,⁶ and the UK.⁷⁻⁹ The Luscombe formula, which was derived from the emergency department (ED) data of the UK in 2005, has been shown to be more accurate than the APLS formula in Australia,³ Ireland,⁵ and the UK.⁸ The APLS formula was consequently updated in 2011. The updated APLS formula incorporates the original APLS formula for use in children aged 1-5 and the Luscombe formula for use in children aged 6-12.¹⁰ Tinning and Acworth also proposed an age-based weight estimation formula, the Best Guess formula,¹¹ based on ED data in Australia between 2001 and 2004. The Best Guess formula has been shown to outperform the original APLS formula in several external validation studies conducted in Australia.¹²⁻¹⁴

The finger counting method, a novel weight estimation method which estimates weight by counting the fingers of both hands, has recently been proposed.¹⁵ The performance of the finger counting method has, however, been inconclusive in the two previous small-scale studies with identical patient numbers (n=207). One study conducted in the US showed the method to be more accurate than the original APLS

formula but less accurate than the Luscombe formula.¹⁵ In another study conducted in Filipino children in the disaster setting, the finger counting method was found to be more accurate than the Luscombe and the updated APLS formulae but less accurate than the original APLS formula.¹⁶

We therefore sought to conduct a large-scale study to evaluate the performance of the finger counting method and to compare its performance with four commonly used age-based weight estimation formulae in Hong Kong children presenting to the ED.

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Methods

Study design and setting

A retrospective cross-sectional observational study was conducted in the ED of Princess Margaret Hospital in Hong Kong between 1 July and 31 December 2014. Princess Margaret Hospital is a tertiary referral hospital in Hong Kong with a mixed adult and paediatric ED managing approximately 20000 paediatric attendances per annum. Ethical approval was obtained from the West Kowloon Cluster Research Ethics Committee of the Hospital Authority.

Study population and data collection

Children aged 1-9 on their last birthday who presented to the ED during the study period were included in this study. ED charts were retrospectively retrieved and reviewed. Data including gender, age, and actual weight were collected. The actual weight of the child was measured using a Seca 770 digital scale (SecaGmbH, Hamburg, Germany) in the ED to the nearest 0.1 kg. Calibration was not required over the study period as the manufacturer recommends servicing the scale every 3-5 years. Children were measured with outer clothing removed; their inner clothing and shoes were not removed. The weight of uncooperative children or children who could not stand was obtained indirectly by subtracting the weight of the parent from the combined weight of the parent and the child-in-arms. The weight measurements were obtained and recorded by ED nurses during triage. Children whose weight was not measured were excluded from the study. For children with multiple ED attendances during the study period, only the first recorded weight was included.

Weight estimation

The weight of the child was estimated using the finger counting method (Figure 1) and four age-based weight estimation formulae (Table 1). Age refers to age of the last birthday of the child.

The finger counting method

The finger counting method is a conceptually simple weight estimation method which estimates weight by counting the fingers of both hands.¹⁵ It is applicable to children aged 1-9. Age of the child (in odd years) is first counted using the left hand, starting at age 1 from the left thumb (Figure 1a and Step 1 of Figure 1b). Weight is counted using the right hand, starting at 10 kg from the right thumb, counting by 5 kg for each finger (Step 2 of Figure 1a and 1b). The corresponding fingers are then matched to give the estimated weight (Step 3 of Figure 1b). For children whose age was an even number, the estimated weight is the average of the estimated weight of the adjacent odd years. A short video description of the finger counting method is available online.¹⁷

Sample size estimation

In previous studies, the mean percentage difference between the actual and the estimated weight of age-based weight estimation formulae ranged 3.1-33.4% with a standard deviation of the mean percentage difference (MPD) of 17.1-31.0%.^{3,5,7,8,18,19} To detect a 5% difference between the actual weight and the estimated weight, assuming the probability of level of statistical significance to be 0.05, the power of the study to be 0.9, and the expected standard deviation the MPD to be 30%, a minimal sample size of 381 children was required.

Outcome measures

The primary outcome was the calculated accuracy and precision of the finger counting method and the age-based weight formulae against the actual weight of children presenting to the ED.

Data analysis

The accuracy and precision of the finger counting method and the age-based weight estimation formulae were evaluated using the Bland-Altman analysis, root mean

squared error (RMSE) as well as the proportions of estimated weights within 10%, 15% and 20% of actual weight. This is in line with the literature where different percentage proportions, including 10%,^{3,4,12,15,18,20} 15%⁵ and 20%,^{12,15,20,21} have been used.

Bland-Altman analysis is a statistical method for assessing agreement between two methods of clinical assessment in which the estimation bias (MPD) and the 95% limits of agreement (LOA) are determined.²² Estimation bias is a measure of accuracy and is indicated by the MPD between the estimated and the actual weight. A positive MPD indicates an overestimation whereas a negative MPD indicates an underestimation of weight. The 95% LOA (calculated as $MPD \pm 2SD$) is a measure of precision, and is the interval within which 95% of differences between the estimated and the actual weight are expected to lie.²² RMSE and proportions of estimated weights within actual weight are overall measures of both precision and accuracy.

Linear regression was performed to derive the best-fit equation to describe the relationship between weight and age. Repeated measures ANOVA with Bonferroni correction for post-hoc pairwise comparison was used to compare the MPDs of the different weight estimation methods. Chi-squared test was used to compare proportions of weight estimates within 10%, 15%, and 20% of actual weight. A p-value of less than 0.05 was considered to be statistically significant. Stata 13.1 (Stata Corporation, College Station, Texas, USA) was used for data analysis.

Results

There were 5541 presentations to the ED by 4334 children aged 1 to 9 years during the study period. Of the 4334 children, 45 (1.0%) children were critically ill (triage categories 1 and 2), and 4289 (99.0%) children were clinically stable (triage categories 3 to 5). Among the 41 critically ill children, 31 (68.9%) had their weight recorded. In contrast, 4160 clinically stable children (96.8%) had their weight measured in the ED ($p < 0.001$). 156 (3.6%) of these children did not have their weight documented and were excluded, leaving a total of 4178 (2368 [56.7%] female) children in the analysis. The median age was 3 years (interquartile range: 2-6 years) and the mean age was 4.0 ± 2.4 years. The mean weight was 17.9 ± 7.6 .kg. Linear regression analysis was used to determine the best-fit line of the study population: $\text{weight (kg)} = 2.65 \times \text{age (years)} + 7.43$.

Table 2 shows the finger counting method had the least overall estimation bias (MPD 0.1%; 95% LOA -34.0% to 34.2%) and was significantly less than that of the four age-based weight estimation formulae (Bonferroni correction, $p < 0.001$). This was followed by the updated APLS formula (MPD -0.4%; 95% LOA -38.5% to 37.8%), the original APLS formula (MPD -7.0%; 95% LOA -38.4% to 24.3%) and the Luscombe formula (MPD 7.2%; 95% LOA -31.8% to 46.2%). The Best Guess formula was the least accurate as it had the largest estimation bias (MPD 10.6%; 95% LOA -27.3% to 48.4%).

The original APLS formula had the narrowest 95% LOA range of 62.8% followed by the finger counting method with a 95% LOA range of 68.0%. The Best Guess formula and the Luscombe formula were less precise with a 95% LOA range of 75.6% and 76.4%, respectively. The updated APLS formula was least precise with a 95% LOA range of 78%. Bland-Altman plots are constructed in Figure 2 to summarise the performance of the finger counting method and the age-based weight estimation

formulae in a graphical manner.

The finger counting method had the smallest RMSE of 4.06 kg and was followed by the Best Guess method of 4.18 kg, the updated APLS formula of 4.20 kg, and the Luscombe formula of 4.22 kg. The original APLS formula had the largest RMSE of 4.75 kg.

The finger counting method had the largest proportions of weight estimates across all percentage proportions of actual weight with 48.6%, 66.3% and 79.7% of weight estimates within 10%, 15% and 20% of actual weight (Table 3). There was no significant difference between the finger counting method and the original APLS formula in all cut-off proportions. In contrast, the updated APLS, Luscombe and the Best Guess formulae had significantly lower proportions of weight estimates across all cut-off proportions of actual weight when compared to the finger counting method ($p<0.001$)

Discussion

To our knowledge, this is the first large-scale study evaluating the finger counting method. This study has demonstrated that the finger counting method outperforms the original and updated APLS formulae, the Luscombe formula and the Best Guess formula in estimating the weight of children aged 1-9 presenting to an ED in Hong Kong.

The study demonstrates the need of an accurate and precise weight estimation method for use in ED. This is particularly relevant in critically ill children as they are less likely to have their weight measured when compared to clinically stable children. In our study, only half of the critically ill children (53.7%) had their weight measured. This is in line with the findings of a previous study in the UK in which only one-fifth (20.6%) of the critically ill children had their weight recorded.⁷

The finger counting method was found to be the most accurate weight estimation method with the least estimation bias (MPD 0.1%). This was followed by the updated APLS formula (MPD -0.4%). In comparison, the original APLS formula moderately underestimated weight (MPD -7.0%), which is consistent with the findings reported in the literature,^{2-9,18} with a greater degree of underestimation reported in Western children (MPD -18.8% to -33.4%)^{3,5,7,8} than Asian children (MPD -7.6%).¹⁸ The Luscombe formula moderately overestimated weight (MPD 7.2%). This is compatible with the findings in Asian children (MPD 7.4%),¹⁸ although the Luscombe formula was found to have a small degree of underestimation in Western children (MPD -2.5% to -6.9%).^{3,5,7,8} The Best Guess formula moderately overestimated weight (MPD 10.9%), and is consistent with the findings in external validation studies in Australia in which the formula was found to overestimate weight between 4.2% and 6.3%.^{12,14}

Consistent with previous studies,^{15,16} the finger counting method was found to be a precise method of weight estimation with a narrow 95% LOA range of 68.0% (95% LOA -34.0% to 34.2%). The finger counting method also has the smallest RMSE when compared to the age-based weight estimation formulae. The RMSE of the finger counting method in our study (4.2 kg) was smaller than that of the original APLS formula (7.5 kg) and the Best Guess formula (5.4 kg) in an Australian study.²³ Furthermore, the finger counting method had the highest proportions of weight estimates within 10%, 15% and 20% of actual weight. This is compatible with a study from the USA in which the finger counting method was found to estimate higher proportions of actual weight when compared to the Luscombe formula and the original APLS formula (the updated APLS formula and the Best Guess formula were not evaluated in that study).¹⁵

In common with Western children, the average weight of Hong Kong children has been increasing over the past few decades.^{24,25} Our study shows that Hong Kong children have outgrown the original APLS formula (which underestimated weight in our population) but have not reached the weight estimates of the Luscombe formula (which tended to overestimate weight in our population). The apparent accuracy of the updated APLS formula came at the expense of age-specific accuracy (which underestimated weight in children aged 1-5 between -3.9% to -7.3% but overestimated weight in children aged 6-9 between 7.1% to 16.1%). In comparison, the finger counting method performed consistently across all ages with the best age-specific and overall accuracy amongst the weight estimation methods evaluated in this study.

The reason behind the superior accuracy of the finger counting method is that the finger counting method – which effectively gives a weight estimation formula of estimated weight = $2.5 \times \text{age} + 7.5$ ¹⁵ – has a much closer approximation to the best-fit formula of our study population (weight = $2.65 \times \text{age} + 7.43$) than both the original APLS and the Luscombe formulae. In fact, the finger counting method is more

closely approximated to the best-fit formula of the Luscombe formula derivation study (weight = $2.75 \times \text{age} + 7.24$) than the Luscombe formula itself.⁷ Such close approximation to the best-fit formula is not attainable in age-based weight estimation formula as any such formula has to be simplified and rounded off to the nearest whole-number integer in order to make it memorable and calculable using mental arithmetic,⁷ with an inevitable loss of accuracy as a result.

There are other advantages of the finger counting method, which requires no specialised equipment, and would therefore be useful in resource poor settings. Unlike the weight estimation formulae, the use of the finger counting method does not rely on practitioner recollection of a mathematical formula. This is particularly important given that the formulae are more likely to be used in stressful situations, like resuscitation, which can contribute to errors.¹⁵ Recollection of the updated APLS formulae among UK paediatric trainees has been demonstrated to be poor (8%).²⁶

Limitations

There are several limitations in this study. Firstly, as the study was conducted in a single ED site it is possible that the results may not be reflective of the population. However, given that the weight-for-age measurements in this study are comparable to that of the most recent territory-wide Hong Kong Growth Survey²⁴ we believe the results of this study would be generalisable to Hong Kong children.

Secondly, the cut-off percentage proportions of weight estimates within actual weight are arbitrary. There is a lack of work demonstrating any clinical difference between the various cut-offs percentage proportions, including 10%,^{3,4,12,15,18,20} 15%⁵ and 20%,^{12,13,20} which have been reported in the literature. In any event, as our result is consistent across different percentage proportions it does not affect our conclusions. Thirdly, as height was not routinely measured in the ED, we could not have compared the performance of length-based weight estimation method such as the

Broselow tape against the finger counting method. One study suggested that the Broselow tape outperformed the finger counting method¹⁶ while the other study suggested that the finger counting method is as accurate as the Broselow tape.¹⁵ Further studies are necessary to compare the performance of the finger counting method against length-based weight estimation method such as the Broselow tape or mid-arm circumference.²⁰ Compared to length-based weight estimation method, the finger counting method, which does not require the physical presence of the child, has the distinct advantage of allowing ED staff to prepare appropriate medications and equipment in advance of the arrival of a critically ill child.

Finally, the finger counting method is only applicable to children aged 1-9 years. In estimating the weight of children outside of the 1-9 age group, ED clinicians should utilise a weight estimation method that best matches the population they are likely to encounter, such as length-based weight estimation method, or other existing weight estimation formulae e.g. the updated APLS formula (1 month-12 years), the Best Guess formula (1 month-14 years) and the Luscombe formula (1-16 years) (Table 1).

Conclusion

The finger counting method outperforms the commonly used age-based weight estimation formulae in estimating the weight of children aged 1-9 presenting to an emergency department in Hong Kong.

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Author contributions

JLTS contributed to the study conception, design, data collection and manuscript

preparation. EPFC contributed to data analysis and graph generation. GNC, CAG and THR contributed to the critical revisions of the manuscript.

Competing interests

None declared.

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Table 1 Age-based weight estimation formulae

Weight estimation formula	Estimated weight (kg)
Original APLS formula ¹	$(\text{age [years]} + 4) \times 2$ for 1-12 years
Updated APLS formula ¹⁰	$0.5 \times \text{age [months]} + 4$ for 1-12 months $2 \times \text{age [years]} + 8$ for 1-5 years $3 \times \text{age [years]} + 7$ for 6-12 years
Luscombe formula ⁷	$3 \times \text{age [years]} + 7$ for 1-16 years
Best Guess formula ¹¹	$(\text{age [months]} + 9)/2$ for 1-12 months $2 \times (\text{age [years]} + 5)$ for 1-4 years $4 \times \text{age [years]}$ for 5-14 years
Finger counting method ¹⁵	$2.5 \times \text{age [years]} + 7.5$ for age 1-9 years*

* Although the use of the finger counting method does not rely on practitioner recollection of a mathematical formula it effectively gives a weight estimation formula as stated above.

Table 2 Mean percentage difference (MPD) and 95% limits of agreement (LOA) of the finger counting method and age-based weight estimation formulae

Age	<i>n</i>	Finger counting method		Original APLS formula		Updated APLS formula		Luscombe formula		Best Guess formula	
		MPD	95% LOA	MPD	95% LOA	MPD	95% LOA	MPD	95% LOA	MPD	95% LOA
1	789	-3.9	(-32.6, 24.7)	-3.9	(-32.6, 24.7)	-3.9	(-32.6, 24.7)	-3.9	(-32.6, 24.7)	15.3	(-19.1, 49.7)
2	718	-3.5	(-28.9, 21.9)	-7.3	(-31.7, 17.0)	-7.3	(-31.7, 17.0)	0.4	(-26.0, 26.8)	8.1	(-20.4, 36.5)
3	616	1.9	(-28.1, 31.8)	-4.9	(-32.9, 23.0)	-4.9	(-32.9, 23.0)	8.6	(-23.3, 40.6)	8.6	(-23.3, 40.6)
4	486	4.0	(-28.4, 36.4)	-4.9	(-34.5, 24.7)	-4.9	(-34.5, 24.7)	12.9	(-22.2, 48.1)	7.0	(-26.3, 40.3)
5	429	4.3	(-30.0, 38.6)	-6.2	(-37.0, 24.7)	-6.2	(-37.0, 24.7)	14.7	(-23.1, 52.4)	4.3	(-30.0, 38.6)
6	351	4.4	(-30.2, 39.0)	-7.2	(-38.0, 23.5)	16.0	(-22.5, 54.4)	16.0	(-22.5, 54.4)	11.3	(-25.6, 48.2)
7	299	3.7	(-38.2, 45.6)	-8.8	(-45.6, 28.1)	16.1	(-30.8, 63.0)	16.1	(-30.8, 63.0)	16.1	(-30.8, 63.0)
8	268	-1.5	(-44.9, 42.0)	-14.0	(-51.9, 23.9)	11.1	(-37.9, 60.1)	11.1	(-37.9, 60.1)	14.7	(-35.9, 65.2)
9	222	-5.5	(-53.4, 42.4)	-18.1	(-59.6, 23.4)	7.1	(-47.2, 61.3)	7.1	(-47.2, 61.3)	13.4	(-44.1, 70.8)
Total	4178	0.1	(-34.0, 34.2)	-7.0	(-38.4, 24.3)	-0.4	(-38.5, 37.8)	7.2	(-31.8, 46.2)	10.6	(-27.3, 48.4)

Table 3 Proportions of weight estimates within 10%, 15% and 20% of actual weight of the finger counting method and age-based weight estimation formulae

Weight estimation formulae	Proportion of weight estimates					
	≤10%	p-value*	≤15%	p-value*	≤20%	p-value*
Finger counting method	48.6%	-	66.3%	-	79.7%	-
Original APLS formula	47.4%	0.283	65.2%	0.310	79.9%	0.828
Updated APLS formula	44.0%	<0.001	61.2%	<0.001	76.0%	<0.001
Luscombe formula	40.5%	<0.001	56.4%	<0.001	70.6%	<0.001
Best Guess formula	39.4%	<0.001	55.4%	<0.001	69.4%	<0.001

*Chi-square test was performed to compare the percentage difference between the finger counting method and age-based weight estimation formulae (the original APLS, updated APLS, Luscombe and Best Guess formulae)

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Figure 1 The finger counting method. Age is first counted from the left thumb (Figure 1a and Step 1 of Figure 1b). Weight is then counted from the right thumb (Step 2 of Figure 1a and 1b). The corresponding fingers of both hands are matched to give the estimated weight of the child (Step 3 of Figure 1b).

Figure 2 Bland-Altman plots for the (a) finger counting method (b) original APLS formula (c) updated APLS formula, (d) Luscombe formula and (e) Best Guess formula. Dotted lines indicate the estimation bias (mean percentage difference) and dashed lines indicate the 95% limits of agreement (LOA). The interval between the dashed lines ($MPD \pm 2SD$) represents the 95% LOA.

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(a)

EMM_12644_F1a.jpg

(b)

Step 3 Match the corresponding fingers of both hands to give the estimate weight

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EMM_12644_F2.png

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