Paediatric weight estimation: validation of the PAWPER XL tape mid-arm circumference method in a South African Hospital

Faculty of Health Sciences, University of the Witwatersrand

Master of Medicine in Emergency Medicine

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MBChB

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Appendices

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SENATE PLAGIARISM POLICY: APPENDIX ONE
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Signature of Student ………………………………………………………………………

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Name of Primary Supervisor Mike Wells

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Article 1: Title: Paediatric weight estimation: validation of the PAWPER XL tape mid-arm circumference method in a South African Hospital

Journal name, year, volume and page numbers: in press.

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Comments by primary supervisor: the contribution by Dr Wu was completely in keeping with first author status.

Paediatric weight estimation: validation of the PAWPER XL tape mid-arm circumference method in a South African Hospital

Masters of Medicine in Emergency Medicine

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Prof Mike Wells

Abstract

Objective

To prospectively compare the performance of the Broselow tape, Mercy method, PAWPER XL tape and the PAWPER XL-MAC method in estimating children's weight in a population of children from a low-income setting. The secondary outcome was to analysis the time taken to perform each method and the improvement in time with practice.

Methods

This was a study in a convenience study sample of 300 children between the age of 0 and 18 years at the Chris Hani Baragwanath Academic Hospital in Johannesburg, South Africa. Weight estimations were obtained using each of the four weight estimation systems on each child. These weight estimations were then compared against measured weight to determine bias, precision and accuracy of the estimation methods.

Results

The PAWPER XL and PAWPER XL-MAC performed the best with the estimated weight within 10% of actual weight (PW10) in 62.7% and 67.3% of cases followed by Mercy method (56.5%) and Broselow tape (43.9%). The use of MAC improved the accuracy of weight estimation especially in heavier and taller children. The median time taken to perform Broselow tape and PAWPER XL tape estimation in the first 10 children were 14.9 seconds and 10.9 seconds respectively. This time taken to acquire weight estimations only improved with the PAWPER XL-MAC and the Mercy method by up to 40.1% and 21.1% in each method respectively.

Conclusion

The PAWPER XL tape and PAWPER XL-MAC method were found to be the most accurate methods of weight estimation in this group of children and adolescents.

Introduction

Therapies directed at children are generally quantified by their body weight. The actual body weight of children presenting in emergency settings or receiving critical care is often difficult or impossible to obtain [1]. This is either due to the need for immediate intervention and resuscitation or due to immobilization. Therefore, an accurate estimation of body weight is often needed, as the accuracy determines the efficacy and safety of the therapeutic interventions [1, 2].

Various length-based weight prediction methods have been developed for children in the past, the most well-known of which is the Broselow tape. This tape is a commonly-used method in the emergency setting due to its simplicity and immediate availability of medication dosages and equipment sizes [3]. It also has significant disadvantages, however. Many studies have shown that the Broselow tape overestimates children's weights in low socioeconomic settings and underestimates the weight of children from higher income countries [4-7]. This can potentially lead to a dangerous degree of drug over- or underdosing. Other than parental estimates, the most accurate current methods of weight estimation are the newer two-dimensional dual length- and body habitus-based systems, such as the Mercy method and the PAWPER tape system [8-10]. The Mercy method uses surrogates of total body length (humeral length) and body habitus (mid-arm circumference (MAC)) to estimate weight. The humeral length and MAC each generate a segmental weight which is read off a table, the values are combined to achieve an estimated weight. This method has been shown to have good accuracy in populations with a high prevalence of obesity as well as populations with a high prevalence of underweight children [11-14]. The PAWPER tape system makes use of a child's body length and a general impression (gestalt visual assessment system) or a figural reference image rating scale (using pictures of children at each habitus score) to assess habitus and provide a weight estimation from the tape [15]. This system is potentially vulnerable to error as different health care workers may have different perceptions of body habitus [16]. For this reason, the PAWPER XL-MAC system was developed, which makes use of MAC to define body habitus, rather than a gestalt impression [17]. Since MAC has previously been shown to be strongly associated with body habitus and is an objective measurement, as opposed to an observer's impression of a patient, its use may increase the accuracy of the PAWPER XL-MAC system when compared to the original PAWPER system [18, 19]. Measuring MAC might take longer to produce a weight estimate, however, which would not be ideal during emergency care.

The aims of this study were firstly to evaluate the weight estimation accuracy and time to obtain a weight estimation for the PAWPER XL tape and the PAWPER XL-MAC method in a population of children from a low socioeconomic background; and secondly to compare the performance of these methods with that of the Mercy method and the Broselow tape (as a past reference standard).

Methods

This study was approved by the Human Research Ethics Committee of the Faculty of Health Science of the University of the Witwatersrand. Informed consent was obtained from the parent or legal guardian and assent was obtained from children who were above 7 years of age.

Study Design

This was a prospective cross-sectional study. The study was conducted from June 2017 to September 2017.

Study Site

The study took place at Chris Hani Baragwanath Academic Hospital (CHBAH) in Soweto, one of the biggest townships in South Africa, situated to the south-west of Greater Johannesburg Metro. Many parts of Soweto rank among the poorest in South Africa.

Study Population

Children from birth to 18 years old who presented to the CHBAH Paediatric unit (outpatients and inpatients), otolaryngology clinic and ophthalmology clinic.

Inclusion criteria:

- All children who were not in need of emergency medical treatment

Exclusion criteria:

- Children whose length could not be accurately assessed. e.g. contractures
- Failure to obtain assent from the child or consent from either guardian or parents

- Children who could not be weighed on a scale
- Children with any known underlying conditions that would produce abnormal body composition (e.g. oedema)

A non-consecutive convenience sample of 300 children was used. This sample size was sufficient to detect a 10% relative difference in accuracy between the weight estimation systems, at a power of 80%, within an accuracy range of 50% to 80%.

Study procedure

Figure 1 shows the study protocol and procedures in which the weight estimations were obtained. Figure 2 provides a description of the use of the PAWPER XL tape and the PAWPER XL-MAC method. A digital electronic scale was used to obtain the participants' actual weight (DQUIP Smart Scale, EF- 8 Series). Participants who were not capable of standing were carried by the data collector and weighed on the electronic scale. The data collector's weight was subtracted from the total weight to obtain the participant's actual weight. The time to complete each measurement method was recorded for the first 10 and last 10 participants. This was done in order to determine the effect of training and practice on the weight estimation times. The researcher is the sole data collector.

Data analysis

The performance of the weight estimation methods was compared with actual weight and against each other. Analyses of the entire study population, as well as for subgroups of weight (≤10 kg, 10.1-20 kg, 20.1-40 kg, >40 kg), age (<2 years, 2-5 years, 5.1-10 years, >10 years) and body habitus score (HS<3, HS3 and HS4, HS>4) were performed. The primary outcome measures included:

- Mean percentage error (MPE) was calculated from the difference between the predicted weights and the actual weight. This gave a measurement of estimation bias.
- Root mean squared percentage error (RMSPE) was also calculated as a measure of precision. It is the average of the absolute (root-squared) percentage errors for each estimation.
- The number of cases that fell within 10% (PW10) and 20% (PW20) of the actual measured weight. This provided a measure of overall accuracy of the methods (i.e. how close to the actual measured weight the estimations were) and was regarded as the primary indicator of overall performance.

Outcome Measures

The primary endpoint was to evaluate the performance of the PAWPER XL method and the PAWPER XL-MAC method in paediatric weight estimation and to compare them with other weight prediction methods in a study sample from a public hospital in South Africa. The secondary endpoint was to analyse the time taken to perform each method and to determine any improvement in time with increasing practice.

Statistical analysis

All data was captured from the data collection sheets and entered onto an electronic spreadsheet (Microsoft Excel for MAC 2011, Microsoft Corporation). Statistical analysis was performed with Stata (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP) for basic descriptive statistics and statistical comparisons. The weight estimation data was described and analysed using the outcomes described above.

Results

A total of 300 children participated in the study. The study included 164 males (54.7%) and 136 females (45.3%). The median and interquartile range (IQR) for age, weight, body mass index (BMI) and BMI-for-age z-score were 4 years (IQR 1.3-8 years), 20.2 kg (IQR 10.2-26.6), 15.9 kg/m^2 (IQR 13.9-17.3 kg/m^2) and -0.8 (IQR -1.9- 0.4) respectively. The demographic and anthropometric parameters of the participants are summarized in Table 1.

Table 2 shows the data for all methods of weight estimation: measures of bias, precision and accuracy for the study participants in subgroups of weight, age and habitus category. In general, the PAWPER XL-MAC showed the best performance statistics, followed by the PAWPER XL tape, the Mercy method and then the Broselow tape. Figure 3 shows the overall accuracy of each weight estimation system (in terms of PW10 and PW20) together with the desired targets for the accuracy outcome measures, as suggested previously [2]. None of the systems achieved the desired benchmark accuracy standards in children under two years of age. The PAWPER XL-MAC method achieved the accuracy standards in children in the 2-5 years group, 6-10 years group and in the above 10 years old group. The Mercy method achieved the accuracy standard in children over 10 years of age. The accuracy standard weight for estimations is considered as 10 percent of actual weight.

Figure 4 shows the analysis of time taken to perform the weight estimation for each method at the beginning and end of the study. Although all methods were used more quickly at the end of the study, only the PAWPER XL-MAC showed a clinically meaningful reduction in time-to-weight estimation of over 40%.

Some participants' weights could not be estimated using the Broselow or the Mercy methods. Forty-five children (15.0%) were too tall for the Broselow tape (Table 3 shows the details of these children). One child (0.3%) was too small for both the Mercy method and the Broselow tape. All participants could have their weight estimated by the PAWPER XL tape and the PAWPER XL-MAC method.

Discussion

Demographic characteristics of the study population

This study population included a large number of young children (nearly 40% were under the age of two years), but also a significant number of older children (a quarter of the children were older than eight years). This was advantageous as the sample included children at the age at which they are most likely to present with severe acute medical illnesses as well as older children who are more at risk for significant trauma presentations. It was thus representative of the type of children who might require emergency weight estimations.

The body habitus categories in this study were predominately HS2 (18.7%), HS3 (34.0%) and HS4 (18.7%). This was somewhat different from the initial PAWPER tape study, conducted in a population of higher economic status, where the children were assigned a body habitus of HS3 (51.4%) and HS4 (22.3%) [20]. In another South African study in a poorer community, Georgoulas et al reported that habitus scores were predominantly HS2 (38.0%) and HS3 (30.7%), similar to that found in this study [13]. Despite the fact that this was a population with a high prevalence of underweight children, there was also a significant incidence of overweight and obese children (20.0%). This allowed for the weight estimation systems to be tested across a wide variety of ages and body habitus types.

Comparison of the performance of the weight-estimation methods

The one-dimensional length-based Broselow tape (arguably the traditional gold standard weight estimation method) had the greatest bias, lowest precision and lowest overall accuracy, which showed its inferiority to the two-dimensional (length-and habitus-based) methods. This can be attributed to the absence of body habitus considerations in the tape's design, as has been shown in previous systematic reviews [2, 8]. This edition of the Broselow tape, the 2011 edition A which is now eight years old, was modified to limit the degree of underestimation in populations from high-income countries. The modifications incorporate revised length based weight estimation based on the United State National Health and Nutrition Examination Data. Unfortunately, the accuracy has shown limited improvement in these children, but worsening of accuracy in populations from low- and middle-income countries [14, 21].

In our study, the Broselow tape tended to overestimate weight in both underweight and "normal weight" categories of children, but it was most accurate in overweight children (HS>4). This was expected, as the Broselow tape has been shown to overestimate weight in a lower socioeconomic setting [6]. A metanalysis on the Broselow tape published in 2017 found the pooled accuracy of Broselow tape to be 54.7% (PW10) [7]. The lowest accuracy was in the low income, high prevalence of underweight group, in which the PW10 was 42.2%. This was consistent with the result of this study in which the PW10 for underweight children was 43.9% [7]. The use of weight adjustment of the Broselow tape using visual estimates of body habitus or measurements such as mid-arm circumference or waist circumference may be needed for the tape to remain relevant [22, 23].

The PAWPER XL-MAC method was the most accurate of all the weight estimation methods. The PAWPER XL-MAC method outperformed the PAWPER XL in older and heavier children, thus suggesting that the PAWPER XL-MAC is a more objective method in older children compared to PAWPER XL tape. Clinical gestalt may be less accurate in assessing habitus, especially in taller and heavier children: the so-called contraction bias, which is the tendency for an observer to underestimate the size of objects (or people) that are larger than average [24]. The PAWPER XL and PAWPER XL-MAC methods' performance both improved with increasing age and body habitus. The PAWPER XL-MAC had its lowest accuracy in the youngest children, where it overestimated weight. This may be at least partly attributed to the difficulty in obtaining mid-arm circumference in younger children due to poor cooperation. The width of the PAWPER XL-MAC is 4 cm, which limited its use to measure MAC in neonates and infants, as the tape was too broad to fit at the midpoint of the arm. In this case the MAC measurements from a regular measuring tape had to be used. Estimated weight correspond to the MAC is read of the PAWPER XL-MAC tape as per child's length. PAWPER XL tape is also made of a sturdy material and does not conform to the natural curvature of the arm as well as a regular measuring tape.

The PAWPER XL and PAWPER XL-MAC had a PW10 of 62.7% and 67.3% respectively. This is different to that of the original PAWPER study in which the PAWPER achieved a PW10 accuracy of 89.2%, the original PAWPER XL validation study in which the PAWPER XL achieved a PW10 accuracy of 83.4% and a study performed by Georgoulas et al, in which the PAWPER tape achieved a PW10 accuracy of 88% REFS. The overall difference in accuracy may be due to difference in study population and the proportion of neonates included in the current study as well as potential accuracy between different users. More than one data collector was involved in the original PAWPER study.

The PAWPER XL tape showed higher accuracy than the Broselow tape and the Mercy method in this study but did not achieve the accuracy reported in previous studies [2,13,14,17]. Similarly, although the PAWPER XL-MAC was the most accurate of the methods tested, it was not as accurate as reported in previous "virtual" studies (studies performed using databases with no prospective use of the system on actual children) [19, 25]. This could possibly improve with standardized training and practice. Human factor or user errors, including potentially those by the data collector in this study, have been shown to be important in weight estimation studies and sufficient training and experience is essential to be able to use any weight estimation system accurately [26, 27].

The Mercy method showed the least bias in the older and thinner children, which was consistent with a previous Australian study, but the most bias in the youngest children [17]. This was expected, as the accuracy of the Mercy method decreases in younger children [14]. Furthermore, the Mercy method was used in supine position in some of the infants which may also have affected its accuracy as has been suggested previously [28]. The Mercy device was originally designed for children aged two months to 16 years old, but the Mercy method was used to estimate the weight of children from birth in this study. The high degree of bias may, therefore, be due to the proportion of neonates included in the study (n=63). However, the Mercy method was still more accurate in our study when compared to the Broselow tape.

Time taken to perform weight estimations in each method

The Broselow tape and PAWPER XL tape were significantly faster than the methods that included a measurement of mid-arm circumference. Both the Broselow and the PAWPER XL tape could provide an estimated weight within 15 seconds from the time of encounter. Methods incorporating the use of MAC (i.e. PAWPER XL MAC and Mercy Method) took more than 30 seconds longer than the non-MAC methods in this study. This is potentially important in an emergency setting where time is limited. The PAWPER XL-MAC system showed the most improvement with practice with an overall improvement of 22.7 seconds (a 40% reduction of the initial time). This confirmed that training and practice can improve the efficiency in the use of the PAWPER XL-MAC method. Only a single previous study has reported the times taken to obtain a weight estimation [28]. In this study the times taken to generate a weight estimation by a group of experienced emergency physicians were similar to the present study, with most weight estimations successfully completed within 30 seconds. In practice the PAWPER XL tape could be used for rapid assessment of the body habitus in an urgent situation and the PAWPER XL-MAC method could then be used to fine tune the measurement once the child was in a more stable condition, if required [29]. However, the differences in time and accuracy are modest and would not be likely to impact on clinical management. Ideally a weight estimation tool should provide the best information immediately that it is used.

Restrictions to weight estimation capability

The Broselow tape can provide weight estimation in children between 46 cm and 143 cm in length with a maximum weight estimation of 36kg. The Broselow tape method recommends that if a child exceeds the length of the tape, adult drug dosages and equipment should be used [3]. Two studies, which examined children of the appropriate age who exceeded the length of the Broselow tape, showed that the actual mean weight of this subgroup did not approximate that of adult weights [30, 31]. Many children in studies involving Broselow tape, often as many as one third of the study sample, had to be excluded as they exceeded the length of the tape [7]. Given the uncertainty of what should be done with children who exceed the length of the Broselow tape, this is a major flaw in the methodology [30]. In our study, 45 children (15%) exceeded the length of the Broselow tape and only five children above the age of 11 years old were able to fit within the length constraints of the tape. Although the Broselow tape is recommended for the use of children up to 12 years old, even in a resource-scarce setting, the tape cannot estimate a significant proportion of the children attending the facility. All the children's weights could be estimated by the PAWPER XL and PAWPER XL-MAC methods, which is an advantage compared with the other methods in this study. It also overcomes the limitation of the original PAWPER tape in this respect.

In summary, the PAWPER XL-MAC method and the PAWPER XL tape were the most accurate weight estimation systems whereas the Broselow tape was the worst performer. The PAWPER XL tape required the shortest time to generate a weight estimate, while the PAWPER XL-MAC method showed the most improvement with practice over the course of the study. The Broselow tape failed to provide a weight estimation in a substantial number of children which was a further limitation of its use. Overall, the PAWPER XL tape and the PAWPER XL-MAC method were the best performers when both accuracy and reasonable speed were considered.

Further studies with more than one data collector, blinding of the investigators to the results of the weight estimation methods as well as the actual weight, and standardisation of the use of various methods may assist in eliminating variability and establishing inter-observer reliability.

Study limitations

In this study, data collection was performed by a single researcher so no comparison of interobserver variability was possible. The clinical gestalt was based on the researcher's perception, which may vary from that of other healthcare workers depending on experience and training. It cannot be presumed that the measurements were performed as reliably and accurately as possible and this aspect might be improved with training and practise. The accepted learning curve is unknown as is at what point it plateaus. This is vital to know to be able to use the instruments as they are intended and requires further research with multiple users. Any estimation tool demands an easy, standard, intuitive technique, that is practicable with all users. This may have limited the accuracy of weight estimation in this study below what might be theoretically possible.

This study population might be different to other populations and the results may, therefore, not be generalisable to other populations. The difference in the performance of weight estimation systems in children of different habitus and age (in particular) means that the performance metrics will differ in populations with a different demographic composition.

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Table and Figure legends

Figure 1 Flow chart for the study data collection procedure and data analysis.

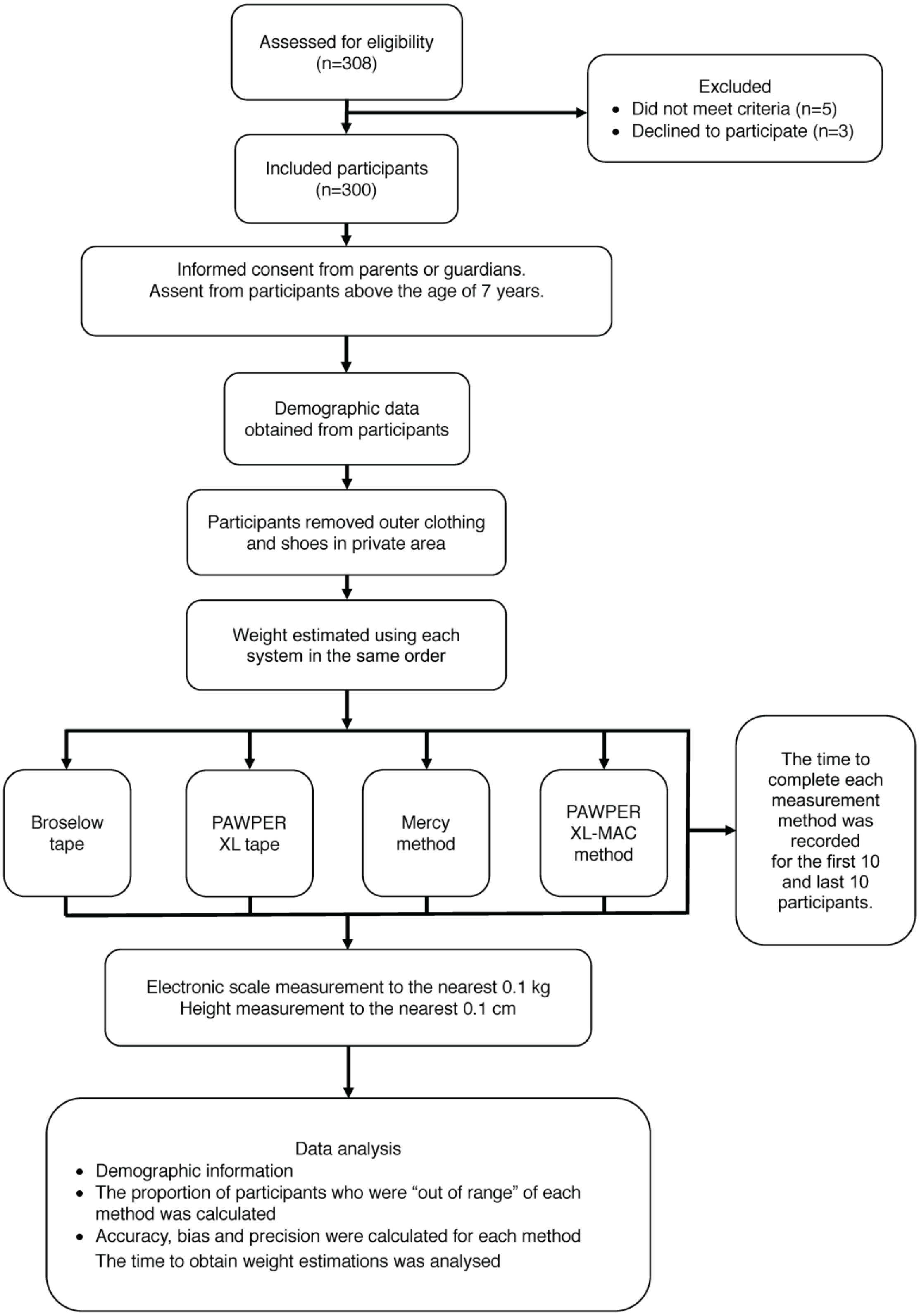

Table 1 Demographic and anthropometric data for the study population. HS – habitus score; IQR – interquartile range with the lower and upper quartiles; BMI – body mass index. A habitus score of <3 indicates an underweight child, habitus score of 3 and 4 are for normal weight children and higher habitus scores are for overweight and obese children.

	All	≤10kg	10.1-20kg	20.1-40kg	≥40kg	HS<3	HS 3-4	HS>4
Total N (%)	300	74 (25%)	118 (39%)	75 (25%)	33 (11%)	82 (27%)	158 (53%)	60 (20%)
Females N (%)	136	38	50	31	17	40	66	30
Males N (%)	164	36	68	44	16	42	92	30
Age (years) median (IQR)	4.0 (1.3-8.0)	0.5 (0.07-1.25)	3 (2.0-5.0)	8 (7-10)	13 (11-16)	7 (4-10)	2 (1.6-8)	2 (1.3-6.3)
Weight (kg) median (IQR)	16.0 (10.2-26.9)	6.7 (4.9-8.4))	14.9 (12.5-17.1)	27.9 (52)	49.8 (44.2-59.9)	20.6 (14.0-29.7)	14.6(9.3-23.9)	14.9 (9.8-20.7)
Z-score (BMI-for-age) median (IQR)	-0.8 (-1.9-0.4)	-1.0 (-1.9-0.2)	-1.0 (-2.3-0.1)	-0.7 (-1.4-0.6)	0,3 (-0.8-1.8)	-2,4 (-3.3- -1.2)	-1.3 (-2.7-0.0)	0.3 (-0.6-1.6)

Table 2 Performance data for all methods of weight estimation. The measures of bias, precision and accuracy for the study participants are shown for each weight, age and habitus category. A positive value of mean percentage error indicates an overestimation of weight. MPE – mean percentage error; RMSPE – root mean square percentage error; SD – standard deviation; PW10 – percentage of weight estimations falling within 10% of actual weight; PW20 – percentage of weight estimations falling within 20% of actual weight; LLOA – 95% lower limit of agreement; ULOA – 95% upper limit of agreement; HS – habitus score.

		Broselow tape	**Mercy method**	**PAWPER XL tape**	**PAWPER XL-MAC method**
ALL n=300	MPE	8.5	6.9	3.3	6.2
	RMSPE (SD)	14.4 (11.5)	11.9 (13.4)	10.4 (8.8)	9.6 (8.2)
	PW10	43.9	56.5	62.7	67.3
	PW20	73.9	84.3	88.3	88.7
	LLOA	-22.1	-25.2	-21.4	-13.9
	ULOA	39.6	39.5	28.5	26.7
≤10kg n=74	MPE	10.5	20.4	4.1	9.5
	RMSPE (SD)	15.4 (13.8)	22.5 (20.6)	12.3 (10.4)	14.0 (9.8)
	PW10	41.7	28.8	52.1	42.5
	PW20	73.6	60.3	79.5	71.2
	LLOA	-27.9	-27.6	-30.1	-23.6
	ULOA	47.1	65.7	36.7	40.9
10.1-20kg n=118	MPE	9.1	4.1	3.9	7.8
	RMSPE(SD)	13.3 (10.4)	9.5 (7.9)	9.2 (6.9)	9.4 (6.4)
	PW10	46.6	60.2	66.1	68.6
	PW20	76.3	89.0	94.9	93.2
	LLOA	-18.9	-18.7	-17.4	-8.6
	ULOA	37.1	26.9	25.2	24.1
20.1-40kg n=75	MPE	8.3	1.7	4.7	4.1
	RMSPE (SD)	13.5 (10.1)	7.1 (5.6)	9.9 (7.8)	6.7 (5.0)
	PW10	46.7	72.0	66.7	81.3
	PW20	75.0	97.3	86.7	97.3
	LLOA	-22.6	-17.8	-20.3	-12.3
	ULOA	38.1	20.3	28.7	19.6
≥40kg n=33	MPE	24.3	2.5	-1.8	0.5
	RMSPE (SD)	24.3 (5.6)	7.6 (7.2)	8.3 (6.6)	4.7 (3.0)
	PW10	0.0	72.7	72.7	93.9
	PW20	33.3	93.9	97	100
	LLOA	-37.7	-17.8	-22.5	-11.7
	ULOA	-10.9	22.7	19.0	12.6
HS<3	MPE	22.9	4.8	11.2	6.7

n=82	RMSPE (SD)	23.6 (12.8)	9.3 (8.4)	14.5 (12.4)	10.7 (11.7)
	PW10	10.0	63.0	39.0	62.2
	PW20	41.7	88.9	76.8	89.0
	LLOA	-4.8	-18.0	-19.4	-21.6
	ULOA	50.7	27.6	41.7	35.0
HS 3-4 n=158	MPE	8.5	7.1	2.6	5.9
	RMSPE (SD)	11.3 (8.7)	12.4 (15.4)	8.2 (7.3)	8.9 (7.6)
	PW10	55.0	57.6	77.2	72.8
	PW20	85.7	85.4	93.7	91.1
	LLOA	-18.0	-30.7	-21.8	-17.9
	ULOA	33.7	43.3	25.9	28.5
HS>4 n=60	MPE	-6.0	11.1	-6.2	5.9
	RMSPE (SD)	10.7 (8.2)	13.8 (12.6)	9.9 (7.4)	9.8 (7.7)
	PW10	56.6	46.7	60.0	63.3
	PW20	83.0	76.7	93.3	85.0
	LLOA	-29.8	-18.7	-27.3	-16.0
	ULOA	17.8	40.8	14.8	27.7
Age <2years n=88	MPE	6.5	17.6	0.8	7.3
	RMSPE (SD)	13.9 (11.9)	20.3 (19.6)	12.4 (13.0)	14.1 (12.8)
	PW10	46.5	36.4	58.0	48.9
	PW20	76.7	63.6	83.0	75.0
	LLOA	-30.9	-28.8	-37.6	-31.0
	ULOA	42.6	61.8	37.8	44.2
Age 2-5 years n=92	MPE	9.4	4.8	4.1	7.9
	RMSPE (SD)	12.8 (9.6)	9.0 (7.7)	8.8 (6.1)	8.8 (5.6)
	PW10	50.0	62.0	66.3	70.7
	PW20	77.2	91.3	96.7	95.7
	LLOA	-17.8	-18.2	-17.0	-7.8
	ULOA	35.8	27.0	24.5	22.9
Age 6-10 years n=76	MPE	11.1	1.7	6.0	5.4
	RMSPE (SD)	15.9 (12.0)	8.1 (6.5)	10.4 (8.6)	7.7(6.5)
	PW10	36.2	65.3	64.0	76.0
	PW20	69.6	94.7	84.0	92.0
	LLOA	-21.2	-18.6	-18.0	-11.4
	ULOA	43.5	21.9	30.0	22.2
Age >10 years n=44	MPE	14.4	2.0	1.5	1.4
	RMSPE (SD)	14.4 (9.9)	7.3 (6.8)	9.0 (6.3)	5.4 (4.4)
	PW10	40.0	72.7	68.2	86.4
	PW20	60.0	95.5	93.2	100
	LLOA	-7.3	-17.3	-19.9	-12.1
	ULOA	36.1	21.4	23.0	15.0

Figure 2 How to use the PAWPER XL tape and the PAWPER XL-MAC method. For the PAWPER XL tape (the left panels): Step 1 – the tape is used to measure the

child’s length from the top of the head to where the tape crosses the heel (this is the same for both systems). The user must take note of the weight segment into which the child falls. Step 2 – the user assesses the child’s habitus using a gestalt impression or with the aid of a habitus-assessment card. Step 3 – the predicted weight is read off from the tape itself from the estimated habitus score. For the PAWPER XL-MAC system (the right panels): Step 1 – the tape is used to measure the child’s length from the top of the head to where the tape crosses the heel. The user must take note of the weight segment into which the child falls. Step 2 – the user measures the child’s mid-arm circumference (MAC) using the tape. Step 3 – the predicted weight is read off the tape from the habitus score category that was determined by the MAC measurements. The cut-off values are shown on the tape.

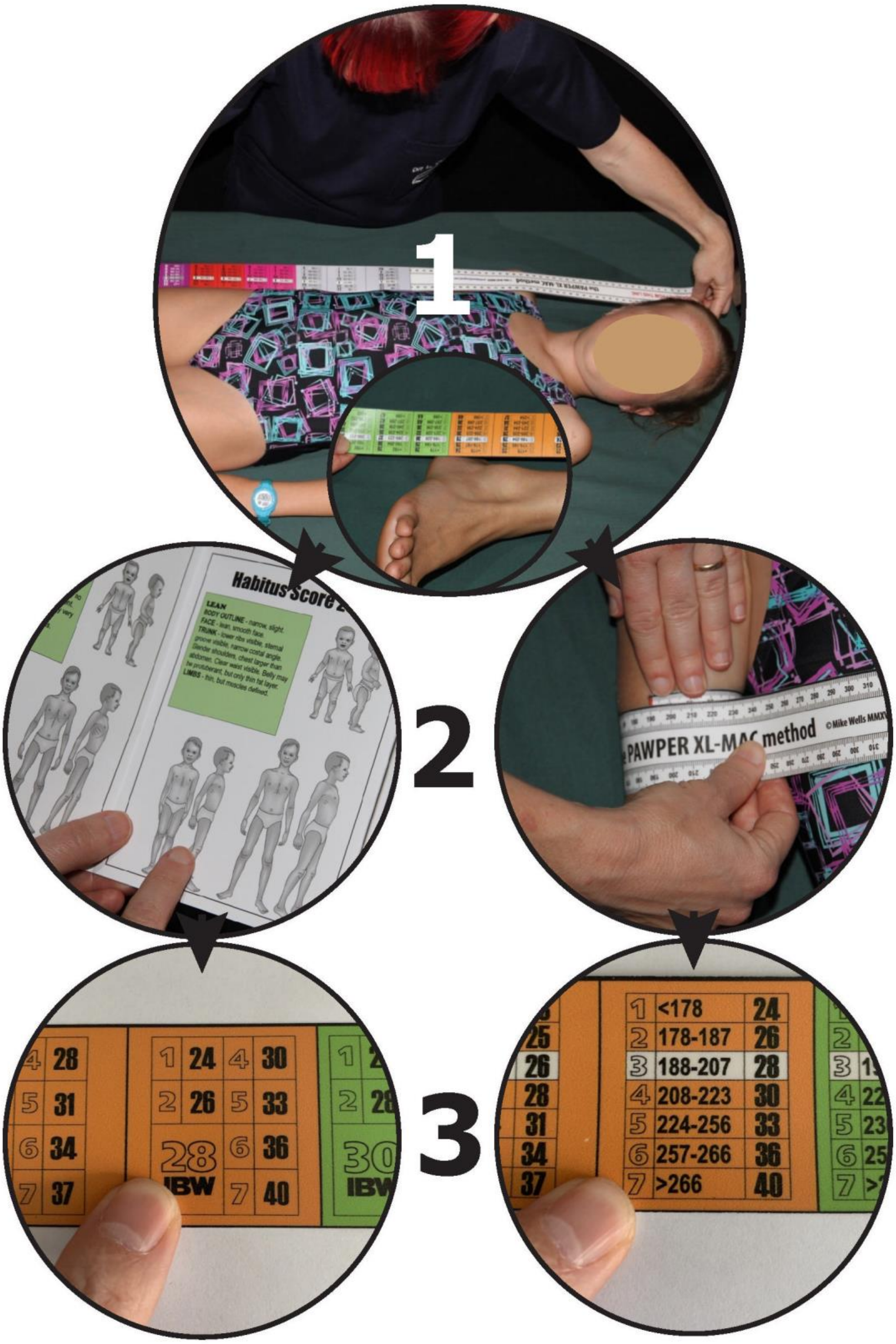
1
2
3
Habitus Score
LEAN
1 24 4 30
2 26 5 33
28 IBW 6 36
7 40
1 <178 24
2 178-187 26
3 188-207 28
4 208-223 30
5 224-256 33
6 257-266 36
7 >266 40

Figure 3 Accuracy outcome data for the weight estimation systems by age-group. The green section indicates the percentage of weight estimations within 10% of actual weight. The red section indicates the percentage of weight estimations that exceed a 20% difference from actual weight. The two dashed lines indicate previously proposed targets for accuracy: the green section (PW10) should exceed 70% (the lower dashed line) and the red section should be above the 95% (the upper dashed line).

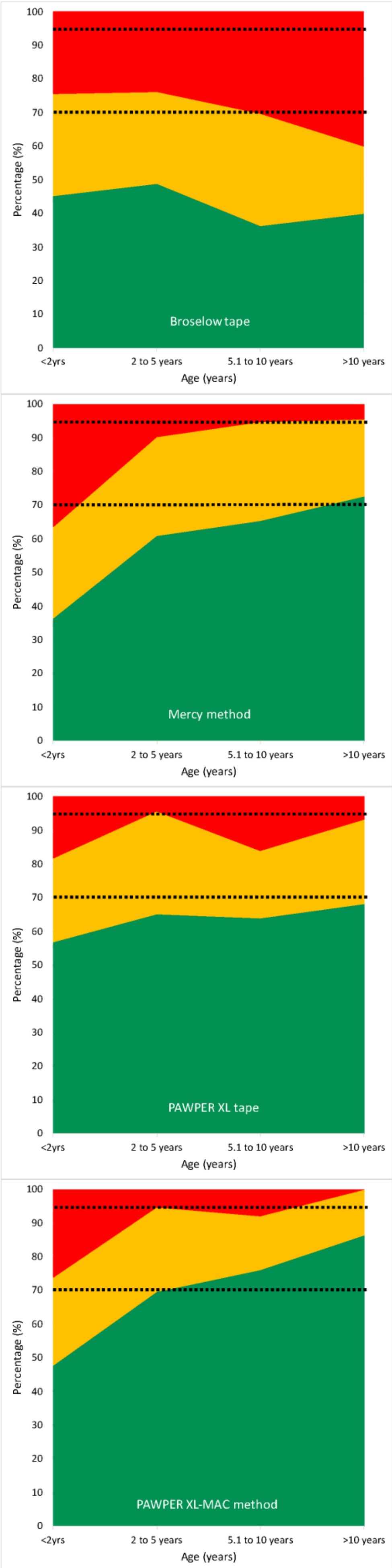
Broselow tape
Mercy method
PAWPER XL tape
PAWPER XL-MAC method
Percentage (%)
Age (years)
<2yrs
2 to 5 years
5.1 to 10 years
>10 years
0
10
20
30
40
50
60
70
80
90
100

Figure 4 An analysis of time taken to estimate weight in the first 10 and last 10 participants. The outcomes of the statistical analyses are shown in the data table below:

	Broselow tape	PAWPER XL	PAWPER XL-MAC	Mercy method
Difference in performance (seconds)	5.1	2.1	24.8	6.5
% improvement in performance	34.2	19.2	43.2	15.9
p for paired t-test	0.0459	0.0309	0.0002	0.0024

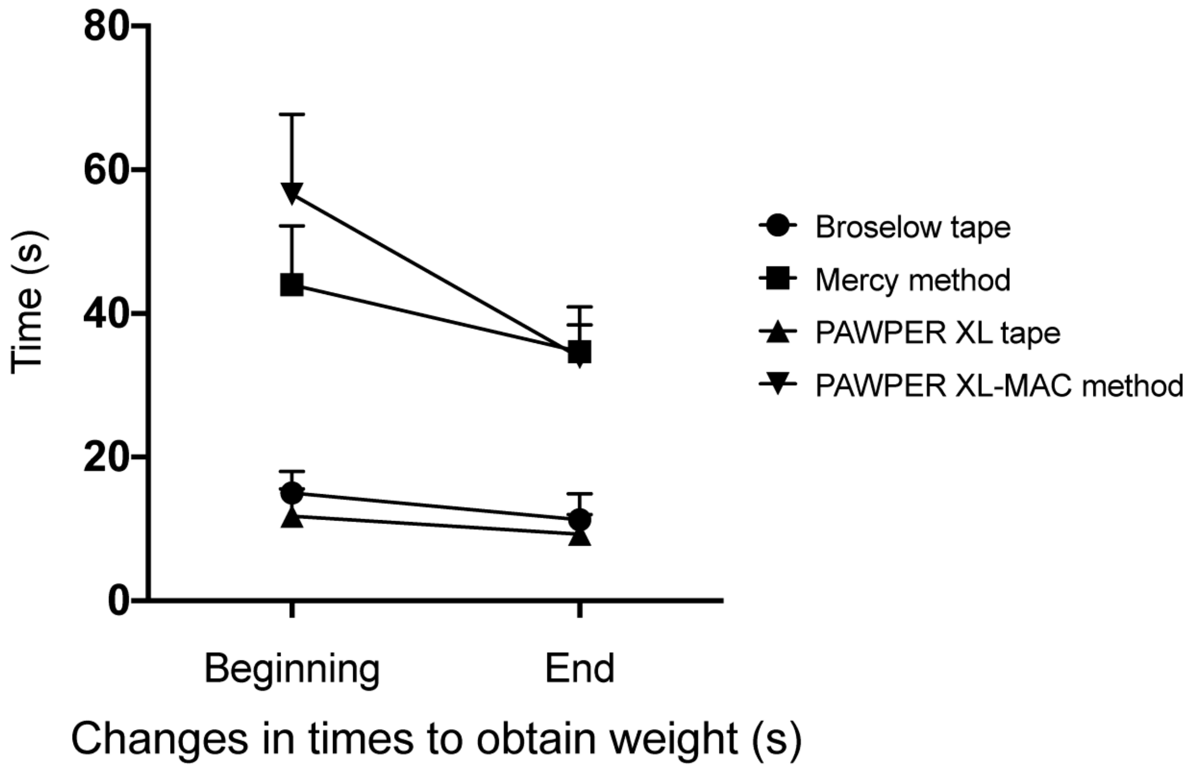

Table 3 Details of the participants who were too tall for the Broselow Tape.

Age (years)	Participants (n)	%	Weight (kg) Median (IQR)	Height (cm) Median (IQR)
8	1	2.2	33.1 (-)	148 (-)
10	5	11.1	31.6 (29.1-32.0)	147 (145-155)
11	8	17.8	45.6 (41.5-59.9)	156 (148-158)
12	9	20.0	36.7 (35.2-41.2)	151 (148-154)
13	6	13.3	45.7 (38.4-52.0)	161 (154-166)
14	3	6.7	62.5 (53.4-71.5)	162 (160-167)
15	1	2.2	46 (-)	160 (-)
16	5	11.1	51.4 (49.8-57.3)	160 (153-166)
17	7	15.6	52.8 (49.7-57.5)	172 (168-173)
All	45	100%	51.4 (36.1-55.7)	155 (150-166)

Paediatric weight estimation: validation of the PAWPER XL tape mid-arm circumference (PTXL-MAC) method in a South African Hospital

Protocol for Masters of Medicine in Emergency Medicine

Introduction

Therapies directed at children are generally weight dependent. The actual body weights of children presenting in emergency settings, or those receiving critical care are often difficult or impossible to obtain.[1] This is either due to the need for immediate interventions and resuscitation, or due to immobilization. However, the accuracy of body weight estimation is imperative as it affects the efficacy and safety of the therapeutic interventions.[1]

Various paediatric weight prediction methods have been developed in the past. Age-based formulas are simple to use but often difficult to remember and tend to underestimate children's actual body weight in developed countries and overestimate weight in developing countries[2]. The use of formulas also increases the cognitive load during resuscitations that can interfere with medical care.[3]The Broselow tape is one of the most commonly use methods in the emergency setting due to its simplicity and immediate availability of dosage require for intervention. The Broselow tape has its own disadvantages. It uses height and weight measurements based on data from the United States' National Health and Nutrition Examination Survey[4] and several studies have shown that the Broselow tape often overestimated children's weights in low social economic settings and underestimates the weight of children from obese populations. [5, 6,7] This is attributed to the absence of body habitus considerations in the tape's design as it is a pure length-based method.[8] Its accuracy is outperformed by the newer dual length and body habitus based methods such as the

Mercy method and the PAWPER tape.[2] The Broselow tape is also limited to measuring children up to 146.5cm, or approximately 12 years of age.

Some of the weight estimation methods that incorporate both length and body habitus of the child into the assessment include:

1. Mercy method – This method, developed in the USA in 2012, uses surrogates of total body length (humeral length) and body habitus (mid-upper arm circumferences (MAC) to estimate weight. This method was initially validated in the USA but has also been shown to have good accuracy when it was externally validated in Mali, India and South Aftica.[9,10,11] It is accurate in populations with a high prevalence of obesity as well as populations with a high prevalence of underweight children.
2. PAWPER tape – This method was developed in 2007 in South Africa. A baseline weight is obtained by measuring the length of the child in supine position, this weight corresponds to the 50th centile of the World Health Organization weight for length growth chart. A body habitus score ranging from 1 to 5 is then assigned to the child based on a gestalt impression of habitus (with 1 representing a thin child and 5 an obese child). The corrected weight is then read off the tape, according to the body habitus score assigned.[8]

Two previous studies comparing the PAWPER tape and the Broselow tape methods in Johannesburg showed that the PAWPER tape estimated weight within 10% of the actual weight in more than 80% of the cases as opposed to the Broselow tape which was accurate in only 50 to 60% of the cases.[8,11] In both these studies, some children were excluded from the study as they exceeded the length of the tapes.[11] The Broselow tape was designed for children between 46 to 146.5cm in length and the PAWPER tape for children between 42 and 150cm in length. The Broselow tape method recommends that if a child exceeds the length of the tape, adult drug dosages and equipment should be use. A study published recently, which studied children of the appropriate age who exceeded the length of the

Broselow tape, showed that the actual mean weight of this subgroup does not approximate to that of adult weights.[13]A longer tape would therefore be required to provide treatment guidance for taller children.

Two studies of the PAWPER tape in populations with a very high prevalence of obesity have recently shown that the tape was prone to underestimate the weight of obese children .[14,15] This work provided the stimulus for the development of the PAWPER XL system. The PAWPER tape XL (extra length, extra-large) (PTXL) is an improved version of the previous PAWPER tape. The changes include an increased length to the tape to provide weight estimation in children up to 182cm in length. The addition of two body habitus scores (habitus scores 6 and 7) allow for improved accuracy in weight estimations in overweight and obese children. One of the other weakness of the original PAWPER tape system, identified in a previous study, is inconsistent assessment of body habitus .[16] The existing PAWPER system makes use of a general impression (gestalt system) or a figural rating scale (pictures of children at each habitus score) to estimate the body habitus of the child and assign a habitus score. This system is subjective and potentially vulnerable to error, which is why the PTXL-MAC system was developed.

MAC has previously been shown to be strongly associated with body habitus.[17] The PTXL-MAC method incorporates a measurement of MAC to provide a more objective assessment of body habitus. The tape is used to obtain a base-weight (in identical fashion to the existing tape system), after which MAC is measured. Each segment of the tape displays MAC values that correspond to each of the seven habitus scores. The appropriate habitus score and corrected weight is then read directly off the tape from these MAC cut-off values. MAC is an objective measurement as opposed to observer’s impression of patient, which may increase its accuracy, but may also take longer to obtain a weight estimate.

Statement of the problem:

The PTXL-MAC has not yet been tested in a prospective validation study and its accuracy and time taken to use it are not known.

Study Aim:

To evaluate the performance of the PTXL method and the PTXL-MAC method in paediatric weight estimation and to compare them with other weight prediction methods in a study sample from a public hospital in South Africa.

Objectives

1. To evaluate the accuracy, bias and precision of the Mercy method, Broselow tape, PTXL tape and PTXL-MAC methods.
2. To compare the accuracy of these weight-estimation methods with each other.
3. To evaluate and compare the accuracy of these methods by subgroups of age
4. To describe and compare the time taken for weight estimation between the different weight estimation methods (Mercy method, Broselow tape, PTXL and PTXL-MAC methods)

Method:

<u>Design</u>

- Prospective cross sectional study

<u>Study Site</u>

Chris Hani Baragwanath Hospital Paediatric department (Outpatient and inpatient department), Otolaryngology clinic and Ophthalmology clinic.

Study Population

All children from birth to 18 years old presenting to the Paediatric unit (outpatients and inpatients), otolaryngology clinic and ophthalmology clinic.

Inclusion criteria:

- All children who are not in need of emergency medical treatment

Exclusion criteria:

- Children whose length cannot be accurately assessed. e.g. contractures
- Failure to obtain assent from the child or consent from either guardian or parents.
- Children who cannot be weighed on a scale
- Children with any known underlying conditions that would produce abnormal body composition (e.g. oedema)

Sampling

- Non-consecutive convenient sampling of 300 children presenting to the Paediatric Department, or who are in-patients at Chris Hani Baragwanath on the days that the researcher is at the hospital
- Subgroups: sufficient numbers of children will be enrolled to ensure that there are at least 100 children in each subgroup to be analysed (<5 years of age, 5 to 10 years of age, >10 years of age)

Measuring instrument

Children will have their weight predicted by the Broselow tape as per standardized technique printed on the tape. They will also have their weight predicted by the PTXL and PTXL-MAC methods as per prescribed technique. A regular measuring tape will then be used to measure children’s humeral length and mid-arm circumference to allow for the calculation of weight estimations by the Mercy method and PTXL-MAC methods. Finally, the child will be weighed on a calibrated digital scale and their weight will be recorded to the nearest 0.1kg. The child's recumbent length will then be measured to the nearest centimetre.

Data Collection

Data and consents will be collected by a single researcher on the appended data collection sheet and consent forms. Data collection will be performed in the following steps:

1. An information sheet will be provided to the participants. (Appendix 1)
2. Informed consents will be obtained from the parent/guardian accompanying the child (appendix 2). Assent will be obtained if the child is above 7 years of age. A tick box is assigned to the data collection sheet to confirm consent is obtained (Appendix 3).
3. The child will remove heavy outer clothing and shoes (and be dressed in a hospital gown or garment if necessary).
4. The date of data collection will be recorded.
5. The age (in years and months) and the sex of the child will be recorded.
6. The weight of the child as predicted by the Broselow tape will be recorded.
7. The weight of the child as predicted by the PTXL tape will be recorded.
8. The weight of the child as predicted by the PTLX-MAC method will be recorded using the child's left arm.
9. The weight of the child as predicted by the Mercy method will be calculated and recorded using the child's right arm (different arms will be used for steps 8 and 9 to allow accuracy of time measurement).
10. Time taken for each prediction methods will be recorded using a standard stop watch and recorded to the nearest second for the first 20 and last 20 children (if required) included in the study.
11. The child will then be weighed on a standard, digital, metric scale that measures to the nearest 0.1 kg. The scale will be calibrated according to the manufacturer's specifications.

12. The child’s length will then be measured using a measuring tape to the nearest 0.5 centimetre.
13. The child’s Body Mass Index (BMI) will then be calculated.

Source of bias

- The actual weight will be measured after the weight prediction has been recorded to avoid bias.
- The order of measurements will be standardized to ensure that the more objective estimations of weight do not influence the other methods.
- Children in need of emergency treatment will excluded from the study. This may potentially produce bias.
- The study will be done at a public hospital that caters to a lower socioeconomic population. The results may not represent children from middle to upper socioeconomic group. A possible limitation is that there may not be enough children with high BMI to be evaluated in the study.

Ethics

Written consent from a parent or legal guardian will be obtained prior to the participation of the research. Assent will be obtained from children above the age of 7 years.

All children and their guardian/parent will receive an information sheet stating the following points

- There is no obligation to participate
- Participation or non-participation will not hinder your child’s treatment
- There are no risks, no discomfort or benefits to any of the individuals participating in the study

Permission to conduct the study will be obtained from the Management of Chris Hani Baragwanath Hospital. Clearance will be obtained from the Human Research Ethics Committee of the University of the Witwatersrand prior to the commencement of the research.

Data Analysis

All data will be captured from the data collection sheets and entered onto an electronic spreadsheet (Microsoft Excel for MAC 2011, Microsoft Corporation).

Statistical analysis will be performed with Stata (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP) for basic descriptive statistics and statistical comparisons.

The weight estimation data will be described and analysed using the following statistics:

- Mean percentage difference plus limits of agreement (MPE plus LOA) – this represents the bias or trueness of the weight estimation system.
- Root mean squared percentage error (RMSPE) – this represents overall precision.
- Percentage of sample predicted within 10 and 20 percent of actual weight (PW10 and PW20) – this represents overall accuracy.

Subgroup analysis of the three age groups will be performed with 100 patients in each group and the same outcome analysis techniques will be used.

Comparisons between the different weight-estimation systems will be performed using ANOVA and chi-squared tests for parametric and categorical data respectively. The Bland and Altman analysis technique will be used to graphically represent the data.

A statistical significance of 5 % level ($p<0.05$) will be used throughout.

Timing

- Protocol will be submitted to the Postgraduate Committee in August 2016
- Ethics will be submitted to the Human Research Ethics Committee of the University of the Witwatersrand in November 2016.
- The study will be conducted from the month of January 2017 to April 2017.
- Manuscript preparation and completion will be accomplished by July 2017.

Funding

All measuring instruments are donated by Dr Mike Wells for the purpose of the study. All cost of the research including petrol, stationary and printing will be bear by the researcher. The cost is estimated not to exceed the value of R3000.

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Appendix 1

Paediatric weight estimation: validation of the PAWPER XL tape mid-arm circumference (PTXL-MAC) method in a South African Hospital

INFORMATION SHEET FOR CHILDREN OVER 7 YEARS OF AGE

Hello, my name is Dr Ming. I am one of the doctors working at this hospital. I would like you to help me with a special project that I am doing. Your mom or dad can stay with you all the time. You will not be hurt during the process. In fact you will help me find out whether this tape can tell me how much you weigh.

Here are the steps:

1. I will ask you to remove your shoes and jacket, but you will not have to get fully undressed.
2. I will be measuring your length from head to toe with 3 different measuring tapes and I will also check how long it take us to measure you with these special tapes.
3. Then I will measure around your arm and also the length of your upper arm.
4. Finally, I will check your weight on a scale.

This will only take a few minutes and I will take down the measurements and put it on a piece of paper. The paper will not have your name on it so you don't need to worry if anyone will find out. I have explained everything to your mom and dad and they are willing for you to help me. It will be nice if you can help me but it is ok if you don't want to.

If you are willing to help me, then please write your name beneath where your mom or dad has signed.

Thank you

Dr Ming-Tung Wu
MBChB
Division of Emergency Medicine, Faculty of Health Sciences, University of the Witwatersrand.
Email address: mingsi86828@gmail.com

Appendix 1

INFORMATION SHEET

Study title: Paediatric weight estimation: validation of the PAWPER XL tape mid-arm circumference (PTXL-MAC) method in a South African Hospital

Good day:

Introduction

My name is Dr Ming-Tung Wu. I am doing research for my Masters of Medicine degree at the University of the Witwatersrand on how to estimate children's weight with tapes. This information will help doctors calculate the right amount of medications to give to children when their weights cannot be obtained through the use of a scale. In this study we want to compare a new tape (called the PAWPER XL-MAC tape) to the other methods.

Invitation to participate

I am inviting you to allow your child to be part my study.

What is involved in the study?

I will be taking measurements on 300 children at this hospital and your assistance can make a difference. I will only take about 10 minutes of your time and the process will not delay your child's treatment and you will not lose your place in the queue (if you are in one). I will be measuring your child's length using 3 different measuring tapes. Then I will measure your child's arm with another tape. I will then measure your child's weight at the end of the process. The time taken for each tape measurement will also be recorded. Your child will need to remove their shoes and outer clothes, but will not be required to undress fully. We will perform the measurements in a private area.

Risks

There is no risk for your child to be involved in the study.

Benefits

There will be no personal benefits from participating in the study. However, the result of the study can assist the future usage of the tape on other children.

Participation is voluntary, Refusal to participate will involve no penalty nor affect your child's treatment. You may discontinue participation at any time without penalty loss of benefits to which the participant is otherwise entitled.

Reimbursements
There will be no monetary reimbursements for your child's participation

Confidentiality
I will record the measurements on a record sheet that will not bear your child's name. The record sheet will only be identified by their serial number. The informed consent form and assent forms will be kept separately from the record sheets as to protect you and your child's personal information. Personal information may be disclosed if required by law. Organizations that may inspect and/or copy this research records for quality assurance and data analysis include groups such as the Research Ethics Committee.

This research has been approved by the Human Research Ethics Committee (HREC) of the University of the Witwaterand. You may contact them for further information.
Chairperson: peter.cleaton-jones1@wits.ac.za Tel 011 717 2301
Administrators - Ms Zanele Ndlovu/ Mr Rhulani Mkansi/ Mr Lebo Moeng Tel 011 717 2700/2656/1234/1252
Email: HREC-Medical.ResearchOffice@wits.ac.za

Contact details of researcher- **Dr Ming-Tung Wu, Division of Emergency Medicine, Faculty of health Sciences, University of the Witwatersrand.**
Email: mingsi86828@gmail.com

Appendix 2

INFORMED CONSENT FOR PARENTS/LEGAL GUARDIANS AND PARTICIPANT ASSENT:

(On behalf of minors under 18 years old)

- Dr Ming-Tung Wu **has provided me with a copy of the Participant Information Leaflet and Consent regarding clinical study Paediatric weight estimation: validation of the PAWPER XL tape mid-arm circumference (PTXL-MAC) method in a South African Hospital**) and has fully explained to me the nature, risks, benefits and purpose of the study.
- The study doctor has given me the opportunity to ask any questions concerning the study.
- It has been explained to me that I will be free to withdraw my child from the study at any time, without any disadvantage to present or future care.
- I have understood everything that has been explained to me and I consent for my child to participate in this clinical study.

PARENT/LEGAL GUARDIAN:

Printed Name	**Signature / Mark or Thumbprint**	**Date and Time**

PARTICIPANT ASSENT: * (Seven (7) years old and above)

Printed Name	**Signature / Mark or Thumbprint**	**Date and Time**

(* Minors competent to understand must participate as fully as possible in the entire procedure)

STUDY DOCTOR:

Printed Name	**Signature**	**Date and Time**

WITNESS (If applicable)**:**

Printed Name	**Signature**	**Date and Time**

VERBAL PARTICIPANT INFORMED CONSENT:

(Applicable when participants cannot read or write)

- I, the undersigned, Dr Ming-Tung Wu have read and have explained fully to the participant, named ....……………………………. and/or his/her legal guardian, ...…………………………………………………, the participant information leaflet.

- The account I have given has explained both the possible risks and benefits of the study. The participant and his/her legal guardian understand these.
- The participant and his/her legal guardian indicated that he/she understands that the participant will be free to withdraw from the study at any time for any reason and without jeopardising his/her subsequent treatment.

I hereby certify that, the participant and his/her legal guardian, acting on his/her behalf, has agreed to participate in this study.

PARTICIPANT:

Printed Name **Mark or Thumbprint (if applicable)** **Date and Time**

STUDY DOCTOR:

Printed Name **Signature** **Date and Time**

PARENT/LEGALGUARDIAN:………………………**(RELATIONSHIP)**

Printed Name **Signature / Mark or Thumbprint** **Date and Time**

WITNESS:

Printed Name **Signature** **Date and Time**

Appendix 3

Data Collection Sheet Date: ____________ Study no.________

1. Consent ☐

   Assent ☐

2. Age: ________ Sex: ________

3. Broselow weight: ________ kg Time: ________s

4. PTXL weight: ________ kg Time: ________s

   HS: ________

5. PTXL-MAC weight: _________kg

   MAC: ________cm Time: ________s

   HS: ________

6. Mercy weight: ________kg Time: ________s

   Humeral length: _______cm

   MAC: _______cm

7. Actual weight: ________kg

8. Length: _______cm

R14/49 Dr Ming-Tung Wu

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M161141

NAME: (Principal Investigator) Dr Ming-Tung Wu

DEPARTMENT: Emergency Medicine
Chris Hani Baragwanath Academic Hospital

PROJECT TITLE: Paediatric Weight Estimation: Validation of the PAWPER XL Tape Mid-Arm Circumference (PTXL-MAC) Method in a South African Hospital

DATE CONSIDERED: 25/11/2016

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Prof Mike Wells

APPROVED BY: Professor P. Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 20/03/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/2nd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated,from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review in November and will therefore be due in the month of November each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

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