Introduction

One of the most important parameters that must be obtained when resuscitating a critically ill or injured paediatric patient is their weight. The dose of emergency medications, the volume of intravenous fluids such as in burns fluid replacement or the amount of blood and blood products to be infused in the hypotensive paediatric trauma victim as well as the equipment to be utilised are all determined by the child’s weight. Ideally, a calibrated scale would be used to obtain an accurate weight, but during resuscitation this would be difficult as patients may be immobilised on spine boards or undergoing emergency interventions such as intubation. Therefore, healthcare providers need a way to rapidly and accurately estimate a child’s weight without impeding or causing delays in resuscitation.

There are numerous ways that have been devised to estimate a paediatric patient’s weight such as guesses, age-based formulae and length-based or dual length- and habitus-based methods. The American Heart Association recommends that, in the absence of measured weight, length-based weight estimations be used. The prototype of length-based weight estimation is the Broselow tape, which, apart from the estimated weight, also provides pre-calculated drug dosages and equipment size recommendations. The major drawback of the Broselow tape is that its drug dosages are based on ideal body weight and not a child’s actual weight. Therefore, there are inherent risks of under- and over-dosing medications in patients with higher or lower than average weight-for-length, respectively. Body habitus needs to be considered as weight based on length alone has the potential to result in substantial drug dosing errors. In order to limit these effects in obese children, the manufacturers of the Broselow tape have suggested the use of a visual estimate to allow the examiner to take the body habitus into account and “bump (the child’s weight) up” a colour zone for weight estimation and drug dosing purposes. The accuracy of this technique has only been evaluated once before.
As a result of the limitations of length-based weight estimation, Wells et al. developed a dual length- and habitus-based weight estimation tool, the PAWPER (Paediatric Advanced Weight Prediction in the Emergency Room) tape, which takes body habitus into account when estimating weight. It allows the examiner to adjust the weight estimation up or down depending on the child’s habitus. It has performed better than the Broselow tape in multiple previous studies.\textsuperscript{2,4,7} The PAWPER tape did not perform as well in a recent study in a very obese population, however, and failed to achieve the same accuracy as in studies in the rest of the world.\textsuperscript{7} As a result, the PAWPER XL tape was developed, which has 7 habitus scores instead of 5 and the length of the tape was extended from 153 cm to 180 cm.\textsuperscript{8}

The hanging leg weight technique was first described in 1990 and was one of the most accurate weight estimations ever reported in its initial study, but no subsequent validation study has been done to assess its accuracy. It is performed on supine children whose fully extended lower limbs are suspended by the heels in a sling hung from a calibrated scale. It uses this weight to predict the actual total body weight from a formula: Estimated weight = 5.176 x Leg Weight (kg) + 3.487.\textsuperscript{9} It is essential that the estimated weight obtained during resuscitation is an accurate weight. The purpose of this study was to determine and compare the accuracy of four paediatric weight estimation modalities in the South African emergency setting: the Broselow tape, a modified Broselow method, the PAWPER XL tape and the hanging leg weight system.

**Methods**

**Study setting**
Our study was conducted in the Chris Hani Baragwanath Academic Hospital paediatric emergency department in Soweto, Johannesburg, South Africa. It is a tertiary institution, which serves a community of low to middle socioeconomic healthcare users.

**Study participants**
A convenience sample of 200 participants between the ages of 1 month and 16 years were enrolled between the period 1 November 2016 and 31 March 2017. This number was predicted to be sufficient and able to detect an absolute difference in weight estimation accuracy of 10% between weight estimation systems, with a power of 80% and 95% confidence. Children that required emergency treatment were excluded. Approval to conduct this study was obtained from the Human Research Ethics Committee of the University of the Witwatersrand (M160631). All parents signed informed consent and assent was obtained from children over the age of seven years.

**Study protocol**
Data was obtained and recorded by a doctor who had received training on the use of the PAWPER XL tape, the Broselow tape and the hanging leg weight technique. The data collection procedure was the same for each child. The child, accompanied by the guardian, was ushered into an examination room. The child was undressed to his or her underwear and their habitus was estimated with the aid of reference images (Figure 1) and recorded. The child was then positioned supine on an examination bed. The Broselow tape was used to estimate weight using its standard methodology (described in Table 1).\textsuperscript{10} Children who were considered to be obese, based on a simple visual assessment of habitus, were “bumped up” a colour zone and this weight was recorded as their modified Broselow tape estimated weight.\textsuperscript{5}

![Figure 1. Visual aid used to estimate body habitus. Image courtesy of Professor Mike Wells.](image)
Habitus Score (HS) 1 represents an underweight child, HS3 represents the normal weight child and HS7 represents the severely obese child. The other habitus scores are for the “inbetweeners”. Each HS has its own predicted weight in each length segment of the PAWPER XL tape. Their weight was next estimated using the standard PAWPER XL tape using the PAWPER methodology (described in Table 1). The children’s legs were then put in a sling and weighed; this was recorded as the predicted weight for the hanging leg weight technique using a Hazlo digital luggage scale (described in Table 1). This scale is accurate for weights between 10 g and 50 kg. It was calibrated according to the manufacturer’s recommendations. Lastly, the children were put on a calibrated scale (SECA 769 COLUMN SCALE) to get their actual weight, which was documented and used as the reference standard.

Data analysis

Basic demographic data was collected. Children were categorised for subgroup-analysis based on their weight-status and age. The weight categories were based on the habitus score (HS): HS3 represented children of average weight, greater than HS3 represented overweight and less than HS3 represented underweight children. These are the same HS shown in Figure 1. Age-categories of children ≤ 5 years, children aged 5 to 10 years and children > 10 years of age were used for subgroup analysis.

The results from the four weight estimation tools were compared to the actual weight (reference standard) using methods that analysed the bias, precision and overall accuracy of the systems. Bias was measured using the mean percentage error (MPE) of the weight estimates. Precision was measured using the Bland & Altman limits of agreement of the MPE and the root-mean-square percentage error (RMSPE). The overall accuracy was represented by the percentage of weight estimates falling with 10% and 20% of actual weight (PW10 and PW20 respectively). Estimated weights greater than 20% above or below actual weight were deemed to be critical errors. The McNemar test was used to compare the accuracy between each weight estimation tool.

Acceptable outcome criteria

A weight estimation system was considered to have performed with acceptable accuracy if it achieved a PW10 > 70% and PW20 > 95%.

Results

Demographic information

There were 200 children enrolled in the study: 113 males (56.5%) and 87 females (43.5%). The median age was 3.0 years (IQR 1.5 – 6.0). The median actual measured weight was 13.4 kg (IQR 8.7 – 19.7). There were 123 children with an average body habitus (HS3) (61.5%), 42 underweight children (21.0%) and 35 overweight children (17.5%).

Accuracy of the weight estimation tools

The Broselow tape could not provide a weight estimate in 7 children (3.5%), as they were too tall for the tape. The PAWPER XL tape was the only weight estimation tool that achieved acceptable accuracy overall, as shown in Table 2. The Broselow tape and the modified Broselow tape techniques achieved intermediate accuracy. The hanging leg weight technique performed poorly in every analysis. Table 3 shows the comparison of the accuracy of the estimation tools using the McNemar test.
Weight category

In each weight category, the PAWPER XL tape showed the lowest bias, narrowest limits of agreement and the greatest accuracy of the weight estimation tools. Its poorest performance was noted in underweight children, with a PW10 and PW20 of 71.4% and 90.5%, respectively. The performance of the weight estimation tools is illustrated in Figure 2.

Age category

The PAWPER XL tape performed the best in all three age categories as illustrated in Figure 3. In children older than 10 years of age, the Habitus Modified Broselow Tape had the lowest bias (-1.8) and predicted weight accurately with 73.7% and 89.5% of estimations within 10% and 20% of actual weight, respectively. However, the PAWPER XL tape was able to predict all of the participants’ weights within 20% of actual weight and 84.6% within 10% of their actual weight. Figure 4 illustrates the percentage of critical errors (weight estimation error >20%) produced by each estimation tool.

Discussion

Study sample demographics

In this study from a low to middle socioeconomic population, there was a high prevalence of average weight children followed by underweight children. This is a similar distribution noted by Georgoulas et al. whose study was also based in a public hospital serving a low to middle socioeconomic class in South Africa. Moreover, Shisana et al. found that 13.5% of South African children are overweight, which is in keeping with our 17.5%, making our sample suitable and probably generalisable to the area and similar populations in South Africa.

Performance of the PAWPER XL tape

The PAWPER tape and PAWPER XL tape were originally developed and validated in South Africa, the latter being the most accurate weight estimation tool in this study. It achieved the acceptable outcome criteria overall, having good accuracy.

Table 3. The overall statistical test outcomes between the weight estimation tools using the McNemar test

<table>
<thead>
<tr>
<th></th>
<th>PW10</th>
<th>PW20</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT vs BT_mod</td>
<td>0.6828</td>
<td>1</td>
</tr>
<tr>
<td>BT vs PTXL</td>
<td>0.0021</td>
<td>0.0037</td>
</tr>
<tr>
<td>BT vs HLW</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BT_mod vs PTXL</td>
<td>0.0101</td>
<td>0.006</td>
</tr>
<tr>
<td>BT_mod vs HLW</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>PTXL vs HLW</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
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BT = Broselow Tape; BT_mod = Broselow tape with modified habitus; PTXL = PAWPER XL Tape; HLW = Hanging leg weight technique.
Figure 2. The accuracy of weight estimation tools to estimate weight within 10% of actual weight in the weight subgroups

Figure 3. The accuracy of weight estimation tools to predict weight within 10% of actual weight in each age category

Figure 4. The overall percentage of critical errors made by each weight estimation tool
in the whole group and every subgroup (see Table 2). It was the most consistent and reproducible tool, with virtually neutral bias (MPE 0.2) and minimal differences between age groups and habitus types. Its poorest performance was in the underweight habitus type, producing a PW20 that did not meet our acceptable accuracy of 95%.

Taking into account its poorest performance, the PAWPER XL tape still performed significantly better than the other weight estimation tools, confirming that length-based estimation tools with body habitus modifications are the most accurate. In our experience, this technique was not user-friendly and is impractical.

Performance of the Broselow tape and a modified Broselow tape system

The Broselow tape is probably the best-known and most widely utilised paediatric weight estimation tool. It has been in clinical use for more than 30 years. Throughout the years and across the world, it has shown to have poor accuracy in estimating weight, especially in children with extremes of habitus. In an attempt to improve the accuracy of the Broselow tape, the manufacturers have suggested that a visual estimate of body habitus can be used to modify the estimate of body weight in overweight or obese children. Overall, in this study, the unmodified Broselow tape did not meet the acceptable accuracy of 95% and the habitus modification thereof improved its PW10 and PW20 by only 2.6% and 0.5% respectively. In overweight children specifically, it improved the PW10 and PW20 by 11.4% and 2.8%, respectively. Furthermore, with the incorporation of the body habitus, the tendency to underestimate obese children decreased from a MPE of -10.4 to -8.3. This is in keeping with numerous studies done in South Africa and internationally showing the tape’s inaccuracy in children of extremes of weights. Despite these improvements, the habitus modified Broselow tape did not meet the acceptable accuracy of 95% and the habitus modification thereof improved its PW10 and PW20 by only 2.6% and 0.5% respectively. In overweight children specifically, it improved the PW10 and PW20 by 11.4% and 2.8%, respectively. Furthermore, with the incorporation of the body habitus, the tendency to underestimate obese children decreased from a MPE of -10.4 to -8.3. This is in keeping with numerous studies done in South Africa and internationally showing the tape’s inaccuracy in children of extremes of weights. Despite these improvements, the habitus modified Broselow tape did not meet the acceptable accuracy of 95% and the habitus modification thereof improved its PW10 and PW20 by only 2.6% and 0.5% respectively. In overweight children specifically, it improved the PW10 and PW20 by 11.4% and 2.8%, respectively.

Critical weight estimation errors

The corollary to a tape performing with acceptable accuracy (PW10 > 70%, PW20 > 95%) is its generation of critical errors. It was not surprising that the hanging leg weight technique had the highest critical error rate of 50%. The Broselow Tape, modified Broselow tape method and PAWPER XL tape critical error rates were 11.4%, 10.9% and 3.5%, respectively (Figure 4). O’Leary et al. found similar results in an ethnically diverse Australian population, with the Broselow tape having a critical error rate of 12.5% and the PAWPER tape maintaining its 3.5% rate. Similar critical errors have been found in studies done in the South African setting as well.

Difficulties experienced with the tools

The Broselow tape was too short for seven of the participants, resulting in weights that could not be estimated. This is a well-documented limitation and disadvantage of the tape, not only in South Africa, but other countries too. The tape is limited between the lengths of 46 to 143 cm whilst the PAWPER XL tape has an upper limit of 180 cm. The PAWPER XL and hanging leg weight technique could be used on all the children, although the latter with some difficulty.

Utility of weight estimation tools in resuscitation

Accurate weight prediction of paediatric patients is crucial to their safe and effective management in the emergency setting. The weight estimation system utilised for this purpose needs to be readily available, easy-to-use and accurate. The PAWPER XL tape was the most accurate and is substantially cheaper in our setting than the other methods analysed.

Limitations

Our study was done in South Africa, Soweto, a low to middle socioeconomic class of people. One can appreciate the potential drawback of using the Broselow tape in such a population, since the tape was developed from North American paediatric growth charts.

One of the major limitations to the study is that it was done in one hospital and may not be generalisable to other populations. The number of participants was also relatively small. Further research on a larger scale is required especially with a greater representation of obese and underweight children.

A single researcher (MM) took measurements and therefore
interobserver variability of the methods could not be assessed.

**Conclusion**

In this study population the PAWPER XL tape was the most accurate weight estimation tool. It performed better than the other weight estimation tools in all categories and met acceptable accuracy in all categories but underweight children. The Broselow tape and a habitus modified Broselow tape system had similar performance but the modified system was understandably slightly more accurate in overweight children. Acceptable accuracy was obtained in the average weight population only. The hanging leg weight technique was grossly inaccurate and is not recommended for clinical use.

In South African paediatric emergencies, the PAWPER XL tape is the most accurate tool for weight estimation.

**References**

6. Wells M, Goldstein L, Bentley A. The accuracy of weight estimation by the Broselow tape can be substantially improved by including a modifier based on a visual assessment of body habitus. Pediatr Res. 18 Oct 2017. doi: 10.1038/pr.2017.222