

An augmented reality mobile application for weight estimation in paediatric patients: A prospective single-blinded cross-sectional study

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ABSTRACT

Introduction: Determining the exact weight of children is a challenging task during emergency situations. Current guidelines recommend the use of length-based weight-estimating tapes. However, healthcare providers must either always carry the tapes or take time to locate them. Moreover, they may not know how to use them. To address these issues, we developed an augmented reality smartphone application for length-based weight estimation called the Paediatric Augmented Reality Scale (PARS). We evaluated its performance and compared it to that of the Broselow tape (BT) and Paediatric Advanced Weight Prediction in the Emergency Room extra-long and extra-large (PAWPER-XL) tape methods.

Method: A prospective, single-blinded cross-sectional study was conducted with children aged 1 month to 12 years who visited the emergency department of the tertiary university hospital in Bucheon, South Korea between July 2021 and February 2022. This study aimed to evaluate the measurement agreement and performance of 3 methods: BT, PAWPER-XL and PARS.

Results: In all, 1090 participants were enrolled, and 639 (58.6%) were male. The mean age of the participants was 4.1 ± 2.8 years, with a mean height of 102.7 ± 21.7 cm and mean weight of 18.8 ± 9.5 kg. Compared to BT and PAWPER-XL, PARS exhibited lower mean absolute percentage error (9.60%) and root mean square percentage error (3.02%). PARS achieved a higher proportion of weights estimated within 10% of the actual weight (63.21%), outperforming BT (57.25%) and PAWPER-XL (62.47%). The intraclass correlation coefficients for the actual and estimated weights of BT, PAWPER-XL and PARS were 0.952, 0.969 and 0.973, respectively ($P < 0.001$).

Conclusion: PARS exhibited a modestly better performance than BT and PAWPER-XL in estimating body weight. PARS-estimated body weights correlated fairly accurately with the actual body weights. PARS holds potential utility in paediatric emergencies.

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Keywords: augmented reality, body weight, Broselow tape, mobile application, paediatrics

CLINICAL IMPACT

What is New

- We developed the Paediatric Augmented Reality Scale (PARS), a mobile application that combines the strengths of the body habitus-adjusted, length-based weight estimation method with the accessibility and convenience of smartphone augmented reality.

Clinical Implications

- The performance of PARS was modestly better than that of the Broselow tape and Paediatric Advanced Weight Prediction in the Emergency Room extra-long and extra-large (PAWPER-XL) tape.
- A mobile application PARS may be useful for paediatric weight estimation.

INTRODUCTION

Drug and defibrillation energy doses for children rely on accurate weight measurement, making it essential during emergencies.^{1,2} However, quickly weighing children in distress is often a challenging task.^{3,4} Conventionally, age-dependent formulas and length-based tapes like the Broselow tape (BT) and Paediatric Advanced Weight Prediction in the Emergency Room extra-long and extra-large (PAWPER-XL) tape, have been utilised.⁵⁻⁸ While the age-dependent method does not require any equipment, it performs less effectively compared to length-based methods.² BT, a widely used length-based method, is employed worldwide to determine optimal drug doses and the necessary dimensions of endotracheal tubes and laryngoscopes.⁵ However, BT has a limited range of applicability, covering lengths from 46 to 146.5 cm, making it less suitable for populations that fall outside this length range, particularly those who are overweight or underweight.^{3,9,10} The

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PAWPER-XL tape takes into account the 7 types of body habitus, making it more suitable for overweight and underweight patients.⁸ However, healthcare providers are required to either carry a tape at all times or locate one when needed. Additionally, there may be instances where providers are unfamiliar with its usage, leading to potential delays in drug administration and increased risk of dosing errors.^{11,12} A survey conducted among paramedics indicated that these disadvantages were significant in emergency situations, highlighting the need for other measurement methods.^{12,13}

Augmented reality (AR) combines digital information with the real environment and enables accurate measurement of object dimensions.¹⁴ AR is widely utilised in various medical fields, including surgical planning and telemedicine, due to its high level of convenience and accessibility.^{15,16} We developed a mobile application called Paediatric Augmented Reality Scale (PARS), which combines the advantages of the body habitus-adjusted, length-based weight estimation method with the accessibility and convenience of smartphone-based AR. In this study, our objective was to assess the accuracy of PARS and compare its performance with that of BT and PAWPER-XL.

METHOD

Study design and setting

This prospective, single-blinded cross-sectional study was conducted with paediatric patients aged 1 month to 12 years who visited the emergency department (ED) of a tertiary university hospital in South Korea between July 2021 and February 2022. The exclusion criteria included the following: height outside of the range of BT (<45.9 or >146.5 cm), a need for emergency intervention, underlying genetic or neuromuscular diseases or congenital malformations affecting height or weight, refusal to participate, and/or an uncooperative child.⁹ The study was approved by the Institutional Review Board (Approval no. 2021-07-005) of the Soonchunhyang University Bucheon Hospital. The study procedure was explained to the participants or their legal guardians, and informed consent was obtained.

PARS

PARS was developed by Bory Inc (Ansan-si, Gyeonggi-do, Republic of Korea) using Google ARCore and Unity 3D. Google ARCore enables an Android smartphone camera to recognise its surroundings by tracking feature points. In ARCore, visual information from the camera is processed through simultaneous localisation and mapping, while movement and rotation information collected

from accelerometers and gyroscopes is processed through the inertial measurement unit. For accurate measurements, it is ideal for the distance between the camera and the child to be similar to the child's height. However, as long as the camera is not too close or too far from the patient, minor variations in distance are not a significant issue. Also, if the camera is positioned between the child's head and toes, the angle at which it is positioned does not matter. Through this process, PARS determines the height from head to heel in a supine position. It is important to note that regional differences may exist in length-based weight estimation methods, as they are based on the World Health Organization (WHO) growth charts.¹⁷ In our study, we utilised the 2017 growth chart from the Korea Center for Disease Control and Prevention (KCDC) for all age groups of our study participants.

PARS utilises a 3-step process for weight estimation. The first step involves obtaining a baseline weight estimation derived from the supine length measured by PARS, similar to other length-based weight estimation methods. This estimated weight corresponds to the 50th percentile of the KCDC weight-for-length growth charts. In the second step, the baseline weight is revised based on the child's body habitus score (HS). A 7-point body habitus scoring system is used to assign a body HS to the child, including HS1 (5th percentile) for underweight, HS2 (25th percentile) for thin, HS3 (50th percentile) for normal weight, HS4 (75th percentile) for overweight, HS5 (95th percentile) for fat, HS6 (97th percentile) for obese, and HS7 (99th percentile) for severely obese.^{6,8} Depending on the child's HS, the baseline weight can be adjusted downwards, upwards or remain unchanged. In the third step, the sex of the child is entered. PARS utilises the length, sex and HS of the child to estimate the weight. Additionally, PARS provides information on emergency drug doses, required equipment dimensions and defibrillation energy. Supplementary Fig. S1 provides detailed instructions on the usage of PARS.

Data collection, measurements and sample size

Weights and heights were measured by a nurse, who was blinded to the aim of the study, when patients visited the ED. The measurements were performed with a precision of 0.1 kg for weight and 0.1 cm for height. Patients usually stood on an electronic scale (HM-201; Fanics, Busan, Republic of Korea) for measurement. In cases where standing was not possible, measurements were taken with the patients in the supine position using a measuring device (BF-100A; Fanics, Busan, Republic of Korea). The collected data, along

with age and sex information, were stored in electronic medical records. A total of 7 ED medical technicians were responsible for measuring the patients' heights using BT (2017), PAWPER-XL and PARS. Prior to the measurements, each technician received 30 minutes of training on the use of these modalities and body habitus scoring. They remained blinded to the actual weights and heights of the patients until all measurements were completed. To estimate weight, the participants were placed in the supine position, and the distance between the top of the head and the tip of the heel was measured. This measurement was used to calculate weight using the respective methods. The sample size for the study was determined based on the assumption that the PARS method would have a PW10 (proportion of weights estimated within 10% of the actual weight) that is 10% better than BT (PW10: 60%), with a power of 80% and a 2-sided risk alpha of 0.05.¹⁸ Consequently, a minimum of 1016 patients were required for the study.

Statistical analysis

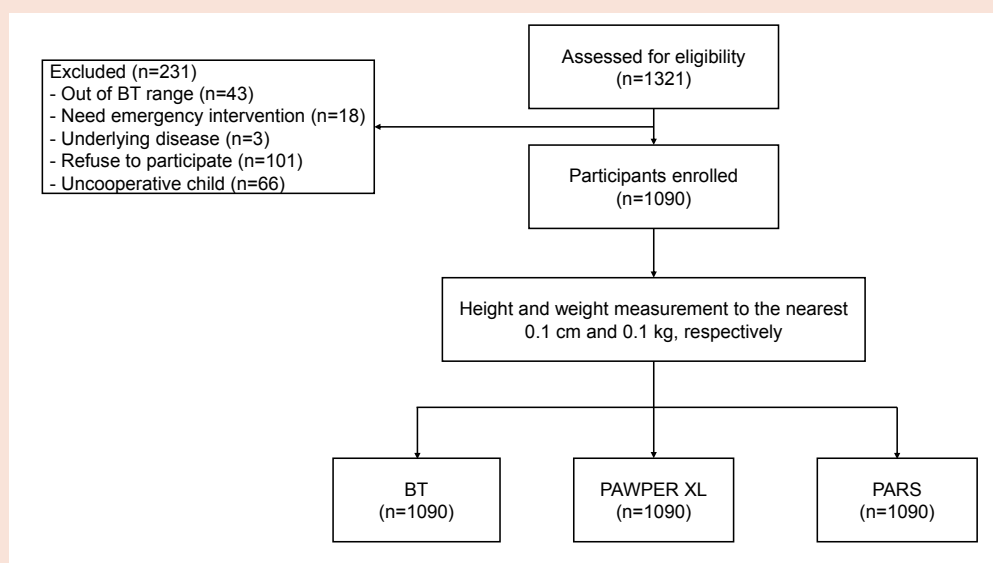
We conducted the statistical analyses using IBM SPSS Statistics version 26.0 (IBM Corp, Armonk, NY, US) and R version 3.5.3 (R Development Core Team, Vienna, Austria) software. Categorical variables are presented as absolute numbers with percentages, while continuous variables are reported as means $\pm$ standard deviations. The participants were divided into 3 age subgroups: 1–12 months, 2–5 years and 6–12 years, for the purpose of analysis.¹⁹ The performance of BT, PAWPER-XL and PARS was evaluated based on the median percentage error

(MPE), median absolute percentage error (MAPE) and root mean square percentage error (RMSPE). MPE assesses predictive bias, while MAPE and RMSPE evaluate predictive accuracy. Additionally, the percentages of weight estimations within 10% and 20% of the actual weights (PW10 and PW20, respectively) were calculated. McNemar test was used to compare differences between PARS and other weight estimation methods (BT and PAWPER-XL). The sensitivity, specificity, positive predictive value and negative predictive value between PARS and the 2 other methods were also calculated. Intraclass correlation coefficients (ICCs) were calculated to assess the agreement between the predicted weight (Wp) and actual weight (Wa). The ICC values were classified as inadequate (<0.7), good ($0.7-0.89$) or excellent (≥ 0.9).²⁰ Furthermore, Bland–Altman plots were constructed to visualise the agreement between Wp and Wa, as well as between the predicted height (Hp) and actual height (Ha). A *P* value of less than 0.05 was considered statistically significant.

RESULTS

We included a total of 1321 Korean paediatric patients who visited our ED during the designated study period. From this initial pool, we excluded 43 (3.3%) patients whose height fell outside the range of BT, 18 (1.4%) patients who required emergency interventions, 3 (0.2%) patients with underlying diseases, 101 (7.6%) patients who declined to participate, and 66 (5%) patients who displayed uncooperative behaviour. The final data comprised 1090 participants (Fig. 1).

Fig 1. Flow chart of patient enrolment.



BT: Broselow tape; PARS: Paediatric Augmented Reality Scale; PAWPER-XL: Paediatric Advanced Weight Prediction in the Emergency Room XL

General characteristics of the participants

Of the 1090 participants, 639 (58.6%) were male. Among them, 108 were aged 1–12 months, 651 were aged 2–5 years, and 331 were aged 6–12 years. The mean age of the participants was 4.1 ± 2.8 years, with a mean height of 102.7 ± 21.7 cm, mean weight of 18.8 ± 9.5 kg, and mean body mass index of 16.9 ± 3.0 kg/m². The distribution of body HS was as follows: HS1, 0 (0%); HS2, 106 (9.7%); HS3, 752 (69.0%); HS4, 184 (16.9%); HS5, 38 (3.5%); HS6, 10 (0.9%); and HS7, 0 (0%) (Table 1).

Performance of BT, PAWPER-XL and PARS

For BT, MPE was -0.45%, MAPE was 11.08% and RMSPE was 3.77%. For PAWPER-XL, MPE was -1.19%, MAPE was 12.52% and RMSPE was 3.78%. Regarding PARS, MPE was 2.59%, MAPE was 9.60% and RMSPE was 3.02%. The limits of agreement for BT, PAWPER-XL and PARS were -6.95 to 7.76 kg, -6.66 to 7.94 kg, and -4.95 to 6.49 kg, respectively. The PW10 was 57.25% for BT, 62.47% for PAWPER-XL and 63.21% for PARS. PARS showed lower RMSPE in the 1–12 months age group (1.05%) and 6–12 years age group (4.63%) compared to BT and PAWPER-XL.

Additionally, PARS exhibited higher PW10 values in all age subgroups compared to BT and PAWPER-XL (Table 2). Moreover, the comparisons of performance and diagnostic accuracy between PARS and the 2 other methods (BT and PAWPER-XL) are shown in Tables S1 and S2, respectively.

Correlations between predicted and actual values

The overall ICCs for BT, PAWPER-XL and PARS were 0.952, 0.969 and 0.973, respectively. Specifically, the ICC for PARS in the 1–12 months age group was 0.940, compared to 0.918 and 0.916 for BT and PAWPER-XL in the equivalent age groups, respectively. In the 2–5 years age group, the ICC was 0.927 for PARS, 0.921 for PAWPER-XL, and 0.908 for BT. For the 6–12 years age group, the ICC was 0.915 for PARS, 0.911 for PAWPER-XL, and 0.816 for BT (Table 3). The Bland–Altman plot demonstrated a narrower limit of agreement and smaller overall mean difference for PARS compared to BT and PAWPER-XL (Fig. 2). The ICC between the H_a and H_p was 0.9986 (95% confidence interval [CI] 0.9984–0.9987) for PARS. The corresponding Bland–Altman plot is presented in Fig. S2.

Table 1. General characteristics of the study participants.

	Total (n=1090)	Aged 1–12 months (n=108)	Aged 2–5 years (n=651)	Aged 6–12 years (n=331)
Age, years	4.1 ± 2.8	0.6 ± 0.3	2.8 ± 1.2	7.8 ± 1.5
Sex, no. (%)				
Male	639 (58.6)	55 (50.9)	378 (58.1)	206 (62.2)
Female	451 (41.4)	53 (49.1)	273 (41.9)	125 (37.8)
Height, cm	102.7 ± 21.7	67.6 ± 8.1	95.8 ± 12.1	127.9 ± 10.2
Weight, kg	18.8 ± 9.5	8.2 ± 2.1	15.0 ± 4.0	29.7 ± 8.8
BMI, kg/m ²	16.9 ± 3.0	17.8 ± 2.6	16.2 ± 2.6	17.9 ± 3.6
HS, no. (%)				
HS1	0 (0)	0 (0)	0 (0)	0 (0)
HS2	106 (9.7)	3 (2.8)	61 (9.4)	42 (12.7)
HS3	752 (69.0)	67 (62.0)	489 (75.1)	196 (59.2)
HS4	184 (16.9)	32 (29.6)	92 (14.1)	60 (18.1)
HS5	38 (3.5)	6 (5.6)	8 (1.2)	24 (7.3)
HS6	10 (0.9)	0 (0)	1 (0.2)	9 (2.7)
HS7	0 (0)	0 (0)	0 (0)	0 (0)

Values are presented as mean $\pm$ standard deviation or no. (%).
BMI: body mass index; HS: habitus score

Table 2. Performances of BT, PAWPER-XL and PARS.

	BT	PAWPER-XL	PARS
All patients (n=1090)			
MPE, %	-0.45	-1.19	2.59
MAPE, %	11.08	12.52	9.60
RMSPE, %	3.77	3.78	3.02
LOA, kg	-6.95 to 7.76	-6.66 to 7.94	-4.95 to 6.49
PW10, %	57.25	62.47	63.21
PW20, %	84.31	87.98	88.72
1–12 months (n=108)			
MPE, %	6.47	1.54	3.53
MAPE, %	12.48	11.13	9.59
RMSPE, %	1.30	1.22	1.05
LOA, kg	-1.79 to 2.87	-2.19 to 2.55	-1.60 to 2.30
PW10, %	47.22	55.56	59.26
PW20, %	77.78	80.56	89.81
2–5 years (n=651)			
MPE, %	-3.06	0.03	2.17
MAPE, %	9.85	9.10	9.18
RMSPE, %	2.22	2.03	2.52
LOA, kg	-4.59 to 4.05	-3.76 to 4.16	-4.34 to 5.34
PW10, %	63.13	66.51	67.13
PW20, %	89.56	91.71	92.01
6–12 years (n=331)			
MPE, %	2.40	4.65	2.90
MAPE, %	13.02	10.79	11.06
RMSPE, %	6.05	4.82	4.63
LOA, kg	-9.70 to 13.1	-6.45 to 10.61	-7.15 to 10.10
PW10, %	48.94	56.50	56.80
PW20, %	76.13	84.29	82.45

BT: Broselow tape; LOA: limits of agreement (95% confidence intervals); MAPE: mean absolute percentage error; MPE: mean percentage error; PARS: Paediatric Augmented Reality Scale; PAWPER: Paediatric Advanced Weight Prediction in the Emergency Room; RMSPE: root mean square percentage error; PW10: percentage of weight estimations within 10% of the actual weight; PW20: percentage of weight estimations within 20% of the actual weight.

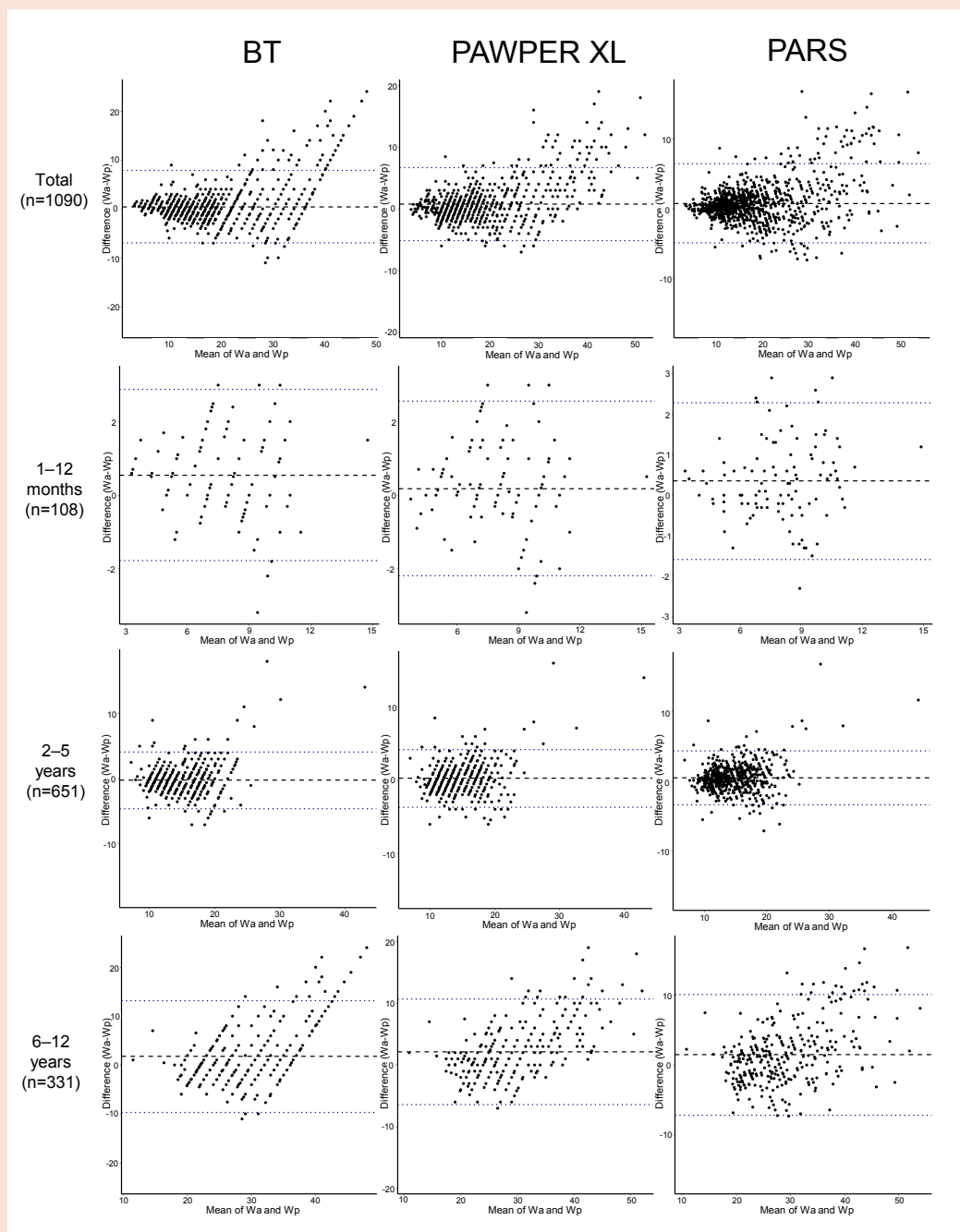
Measures of bias, precision and accuracy are shown by age group.

Table 3. Correlations between estimated and actual weights in various age subgroups.

	BT			PAWPER-XL			PARS		
	ICC	95% CI	P value	ICC	95% CI	P value	ICC	95% CI	P value
All patients (n=1090)	0.952	0.946–0.957	<0.001	0.969	0.966–0.973	<0.001	0.973	0.969–0.976	<0.001
1–12 months (n=108)	0.918	0.88–0.944	<0.001	0.916	0.878–0.943	<0.001	0.940	0.911–0.959	<0.001
2–5 years (n=651)	0.908	0.892–0.921	<0.001	0.921	0.907–0.932	<0.001	0.927	0.914–0.937	<0.001
6–12 years (n=331)	0.816	0.772–0.852	<0.001	0.911	0.889–0.928	<0.001	0.915	0.895–0.932	<0.001

BT: Broselow tape; CI: confidence interval; ICC: intraclass correlation coefficient; PARS: Paediatric Augmented Reality Scale; PAWPER: Paediatric Advanced Weight Prediction in the Emergency Room. $P < 0.05$ was taken to indicate statistical significance.

Fig. 2. Bland–Altman plots for all weight estimation methods with 95% limits of agreement.



Wa: actual weight; Wp: predicted weight

DISCUSSION

We evaluated the weight-estimating AR application PARS and obtained the following key findings. The weight estimates provided by PARS exhibited favourable agreement with the actual weights, and PARS demonstrated modestly higher accuracy compared to BT and PAWPER-XL tapes. Moreover, the estimated body weights obtained through PARS displayed significant correlations with the actual body weights. It is worth noting that previous smartphone applications have also demonstrated high PW10 values.^{18,21,22} However, a previous application developed by Wetzel et al. had the limitation of requiring a 20×20 cm square to be positioned adjacent to the patient.²¹ Another application developed by Park et al. exhibited a superior PW10 value compared to PARS, but it had the drawback of necessitating a significant amount of space and the positioning of 4 red markers (150×38.5 cm) at regular intervals.¹⁸ A recent study using ARKit found that the proportion of height estimations within a 20% range of the accurate values was 99.6%. However, it should be noted that the study did not include overweight and underweight patients.²² PARS offers convenience, as it eliminates the need for additional reference objects, enabling accurate body weight estimations for both underweight and overweight patients by adjusting the HS.

PARS demonstrated superior accuracy, precision and bias compared to BT across all age groups, likely due to its adjustment of length-based weight estimations based on the HS, similar to PAWPER-XL.^{18,23} The PAWPER-XL tape utilises WHO growth charts derived from surveys conducted in various countries, including the US, Oman, India, Norway, Ghana and Brazil, which may limit its suitability for other nations. Previous research has indicated that utilising local growth charts is more advantageous than relying solely on WHO charts. In fact, a study assessing a Korean paediatric population recommended the use of a Korean growth chart for children aged over 24 months, despite utilising a WHO growth chart for evaluation purposes.^{17,24} Therefore, we employed the KCDC growth chart, which could account for the modestly superior performance of PARS compared with PAWPER-XL.

For accurate weight estimation, it is crucial for PARS to fulfil the PW10 (60–70%) and PW20 (90–95%) criteria.^{8,25} The PW10 and PW20 values of PARS for all patients were 63.21% and 88.72%, respectively, which were comparable to the reference values. These values outperformed those of PAWPER-XL. It is worth noting that the KCDC 2017 and WHO Growth Chart indicate that males and females with the same height and body HS exhibit variations in weight.^{24,26}

Thus, PARS, which takes into consideration sex differences, may perform better than PAWPER-XL, which does not consider sex differences.^{24,26} However, the PW10 and PW20 values of PARS for the 6–12 years age group were inferior to those of the other age subgroups, likely due to the AR application not handling longer surfaces effectively.²⁷ PAWPER-XL and PARS demonstrated lower PW10 and PW20 values for the 6–12 years age group compared to the 2–5 years age group. These findings are consistent with recent studies utilising PAWPER-XL that have reported similar results.^{28,29} The decrease in accuracy is likely attributed to the inaccurate evaluation of body HS in obese school-aged children.^{30,31}

The ICC reflects the variability between variables and the measurement error. The overall ICC for Wp and Wa using PARS was 0.976 (≥ 0.9), indicating excellent agreement.²⁰ However, the ICC for Wp and Wa using BT was significantly lower for school-aged children (6–12 years). A previous study found that the rate of obesity increased with age in schoolchildren but not in preschool children.³² The ICC values for Wp and Wa in the 6–12 years age group were higher for PAWPER-XL and PARS than for BT. This is likely because the former values were adjusted based on body HS. However, careful interpretation of ICC value is required that a low ICC implies poor agreement/accuracy, whereas a high ICC does not guarantee good agreement/accuracy.

PARS is a length-based weight estimation method, similar to BT and PAWPER-XL, but it has distinct strengths. First, PARS is highly accessible. Smartphone medical applications are widely used by healthcare providers worldwide.³³ PARS will assist healthcare providers in emergency situations inside and outside of hospitals. Second, PARS is highly portable, as it does not require additional reference objects like existing smartphone applications.^{18,21} Last, PARS is accurate, as it considers underweight and overweight statuses.

Limitations

This study had several limitations. First, it was conducted at a single centre in South Korea, which may limit the generalisability of the findings to other countries or populations. The use of PARS in different countries may be restricted due to its reliance on the KCDC growth chart. Thus, the growth parameters obtained may not be accurate for other populations. Second, our study only included relatively stable patients who did not require emergency treatment. This limits the applicability of PARS in situations where patients have uneven surfaces due to the presence of other medical instruments, such as spinal boards or

splints. One potential alternative approach could be marking 2 points parallel to the direction of the child's head and feet using PARS and measuring the distance between these points. Further investigation is needed to assess the utility and accuracy of PARS in patients who are severely injured or ill. Third, a factor that adjusts for the potential inaccuracies in assessing body HS is needed for PARS, similar to how PAWPER-XL-MAC considers mid-arm circumference.³¹ Fourth, we did not analyse the required time for weight estimation when using PARS compared to BT and PAWPER-XL. Fifth, there are limitations regarding the absence of participants corresponding to HS1 and HS7, and the unequal distribution of lighter and heavier children across each age subgroup. Further research is needed to address these limitations.

CONCLUSION

PARS exhibited a modestly better performance than BT and PAWPER-XL in estimating body weight. The PARS-estimated body weights correlated fairly accurately with the actual body weights. PARS holds potential utility in paediatric emergencies.

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