Regression Equations for Weight Estimation in Paediatric Resuscitation

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Abstract. *Background*: Weight estimation is critical in paediatric resuscitation, as stopping to weigh a child could influence their survival. Weight estimation methods used in New Zealand (NZ) are not accurate for the population, increasing the complexity of prescribing medication and selecting equipment. *Aim*: Develop regression equations (RE) to predict the weight of NZ children based on height, sex, age and ethnicity to be deployed in a mobile application (Weight Estimation Without Waiting). *Methods*: The RE was derived from retrospective regression modelling of a large existing dataset. Data were presented using descriptive statistics and calculation of means, limits of agreement and the proportion of weight estimates within a percentage of actual weight. *Conclusion*: The RE developed in this study outperformed existing age-based weight estimation methods while providing a method to ensure that weight estimation techniques evolve with NZ children.

Keywords. Weight estimation, paediatric, resuscitation, New Zealand

1. Introduction

During paediatric resuscitation, weight is used to determine medication doses and equipment size and as a result, weight estimation techniques have become widely used when stopping to weigh a child could impact their survival.[1] This study presents the development of regression equations (RE) to predict a child's weight based on height and demographic data for use in paediatric resuscitation. The RE were deployed in a mobile application (Weight Estimation Without Waiting) which used Augmented Reality to measure the length and calculate children's weight.[5]

2. Background

In New Zealand (NZ), the NZ Resuscitation Council (NZRC) advises clinicians on weight estimation in resuscitation.[17] Age-based weight estimation methods endorsed by the NZRC[17] and St John Ambulance[22] are based on the advanced paediatric life support (APLS) formula.[21] For children aged 1–9 years, this is (2 x [age in years + 4]). For children under one year, they both advise estimating weight as 5 kg. However,

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recommendations differ for children aged 10–14 years; the NZRC suggests age in years × 3.3, whereas St John advises age in years × 3.

Annually, over 154,000 children under 15 years present to an NZ emergency department (ED).[15] While the proportion of presentations that require resuscitation is unclear, one study of NZ and Australian children found that 27% required care immediately or within 10 minutes of arrival.[2] Applying this to NZ ED presentations, 41,500 children may receive treatment based on a weight estimate each year.

Inaccurate weight estimation can lead to medication dose errors. For example, 34% (125/360) of medication errors were related to a dose miscalculation during pre-hospital cardiac arrest.[10] When multiple calculations are required (e.g. weight estimate plus dose calculation), compounding errors may occur. Mobile technology offers a possible solution that could reduce the risk of errors or alleviate the need for ad-hoc adjustments based on a clinician's perception.

3. Methods

Statistics NZ supplied an existing dataset containing the age, gender, height, weight, and ethnicity of NZ children.[23] As the dataset was already deidentified, ethics approval was waived for this study. The sampling framework and protocol for data collection were published and the sample was shown to be representative of the NZ population.[16] The dataset initially contained 23,217 records. Children over 14 years were excluded, ambiguous records and outliers were removed based on z-scores for height and weight, leaving 17,401 records for analysis.

The dataset was randomly split into two subsets: the *regression dataset* (n = 8467) and the *test dataset* (n = 8413). Using SPSS (version 24)[11] regression analysis was performed on the regression dataset to derive the RE, with the fit and accuracy of the RE calculated. The mean, SD and Confidence Intervals of 95% were applied during linear regression modelling of variables weight, age, sex, ethnicity, and height to formulate the RE. SPSS automatically removed outliers based on a large Cooks distance. Results of the regression were translated into an equation for each variable, where B represents the unstandardised beta coefficients for each variable, height (cm), age (years), ethnicity (Maori, Pacific, Asian & Other) and sex (male & female). The equation to predict weight:

$$weight = \beta 0 + (\beta 1 \times Height) + (\beta 2 \times Age) + (\beta 3 \times Gender)$$

The RE was used to calculate a weight estimate for each child in the test dataset. Data analysis was via descriptive statistics; internal consistency was checked using Cronbach's alpha and the sample distribution was evaluated using skewness and kurtosis.

4. Results

An overview of the test dataset is shown in Table 1, Table 2, and Table 3.

Table 1. Demographic characteristics test dataset.

	2	3	4	5	6	7	8	9	10	11	12	13	14
n	692	690	686	657	660	625	646	599	598	625	648	607	680
%	8.23	8.20	8.15	7.81	7.85	7.43	7.68	7.12	7.11	7.43	7.70	7.22	8.08

Table 2. Distribution of gender (sex).

Sex		
	n	%
Male	4343	51.6
Female	4070	48.4

Table 3. Distribution of ethnicity.

Ethnicity		
	n	%
Maori	3062	36.4
Pacific	798	9.5
Asian	814	9.7
Other	3739	44.4

All variables in the *test dataset* were distributed normally[12], while age, sex, ethnicity height showed a skewness between −1 and 1, weight was positively skewed (skewness 1.139) and all skewness variables had a SE of 0.026. For kurtosis, all variables were within 1 SD with a SE of 0.053. The mean SE of predicted weight is 0.226 with no residual outliers. The adjusted R^2 indicates that all equations have 80% or above accuracy.

Comparison of weight estimation research is challenging due to multiple reporting methods. Therefore, results were presented via mean percentage error (MPE), limits of agreement (LoA) and percentage of weights within 10%, 20% and 30% of actual weight.

Table 3 shows RE are that the most accurate weight estimation method (mean error 11% lower than other techniques). Interestingly, the SD is lower in some existing weight estimation methods, and future research is planned to improve the SD of the RE.

Table 4. Comparison of RE weight estimation based on the mean percentage error.

	St John		NZRC		RE	
Ethnicity	MPE	SD	MPE	SD	MPE	SD
Maori	24.8	16.6	22.4	16.6	-0.9	23.7
Pacific	31.4	16.3	29.1	16.2	-0.1	26.2
Asian	15.2	16.7	12.4	16.7	-1.2	23.2
Other	18.4	15.5	15.3	15.8	-1.4	22.3

Table 4 compares the proportion of weight estimates within 10%, 20% and 30% of the actual weight, where the RE weight estimates outperform all endorsed methods.

Table 5. Comparison of weight estimation within 10%, 20% and 30% for children aged 2–14 years.

Estimation method, Statistics New Zealand data[23]]	Percent of estimates within a given percentage of the actual weight			
	n	±10%	±20%	±30%
All	8413	36.5	70.9	100
Ethnicity	8413	41.1	76.1	100
NZRC	8413	35.4	71.8	100
St John	8413	33.6	70.4	100

The LoA with 95% CI (Table 5) indicate RE outperformed all other estimation methods.

Table 6. Limits of Agreement (LoA) for the Statistics New Zealand dataset (15) weight estimates.

		Difference		LoA	
Estimation method	n	Mean	SD	Upper	Lower
NZRC	8679	8.92	11.68	31.82	-13.97
RE	8679	-0.03	8.93	17.46	-17.52
St John	8679	10.30	12.47	34.74	-14.13

5. Discussion

Weight estimation is critical in paediatric resuscitation, as stopping to weigh a child could influence their survival. Resuscitation is prone to error[8] as it is time-critical, decision-dense, chaotic, crowded and noisy, with multiple teams working in the same physical space[13; 14] which can distract clinicians from a task or decision.[18]

Over 50% of children who have their weight estimated using methods endorsed for use in NZ[17; 22] are at risk of receiving non-therapeutic medication doses or non-optimal equipment size due to inaccurate weight estimates. Internationally, the accuracy of paediatric weight estimation tools is well researched. However, in NZ, research is limited to two Auckland studies. In 2005, the APLS formula significantly underestimated the weight of Māori and Pacific children (n = 909),[24] and in 2015 was again inaccurate for 60% of (n = 397) children aged 5–10 years.[6]

The clinical significance of the inaccuracy of weight estimates shown in both studies is difficult to determine, as there is no research into the prevalence of weight estimation during resuscitation in NZ. Similarly, international studies showing the prevalence of weight estimation are minimal. One 1997 UK study reported that only 2% (2/100) of children were physically weighed before receiving resuscitation medications.[9] This implies that 98% of children had a medication administered based on a weight estimation.

The NZRC recommends age or length-based methods for estimating the weight of non-obese children yet only length-based methods for obese children[17] which means clinicians need to determine obesity before selecting a weight estimation method. These decisions complicate the resuscitation process as the NZRC does not define obesity or indicate which length-based weight estimation method is optimal. Moreover, this means that clinician perception of obesity and technique choice could alter the accuracy of weight estimates.[7; 8; 13; 14] The RE developed in this study eliminate the need to determine obesity or choose an estimation method, thus reducing the risk of error.

Changes in the body composition of children over time are not always mirrored in the evolution of weight estimation methods. For example, two novel mobile applications that streamline paediatric weight estimation[4; 25] use existing weight estimation methods, increasing the disparity between the population and weight estimates. A similar disparity is evident in weight estimation in NZ [17; 22] as techniques are generally based on the APLS formula, which has been static for 20 years[3] despite changes in children's adiposity and anthropometric measures within that time.[19; 20]

The RE developed in this study improve the accuracy of age-based weight estimates. However, population data in the development of RE can cause a lag in translation to clinical practice. Publication of the method used to develop RE may reduce the risk of error by lag, allowing weight estimation methods to evolve with children over time.

6. Conclusion

This study has shown that the development of RE using demographic data can improve weight estimation accuracy. Overall, the RE outperformed the NZRC and St John weight estimates across and is well-placed to estimate NZ children's weight aged 2–14 years. Furthermore, the process used to the RE promotes replicability and means that weight estimation RE can evolve with the population over time.

References

[1]   *Advanced Paediatric Life Support: The Practical Approach*, 2012.

[2]   J. Acworth, F. Babl, M. Borland, P. Ngo, D. Krieser, J. Schutz, R. Pitt, E. Cotterell, S. Jamison, J. Neutze, and M. Lee, Patterns of presentation to the Australian and New Zealand Paediatric Emergency Research Network, *Emerg Med Australas* **21** (2009), 59-66.

[3]   R.H. Alexander and H.J. Proctor, *Advanced trauma life support program for physicians*, American College of Surgeons, Chicago, IL, 1993.

[4]   N. Appelbaum, J. Clarke, I. Maconochie, and A. Darzi, Paediatric weight estimation by age in the digital era: optimising a necessary evil, *Resuscitation* **122** (2018), 29-35.

[5]   S. Britnell, *Weight Estimation without Waiting: Design, Development and Testing of a Mobile Application to Measure the Length and Estimate the Weight of New Zealand Children for Advanced Paediatric Resuscitation*, Auckland University of Technology, 2020.

[6]   S. Britnell and J. Koziol-McLain, Weight estimation in paediatric resuscitation: A hefty issue in New Zealand, *Emerg Med Australas* **27** (2015), 251-256.

[7]   P. Croskerry, Achieving quality in clinical decision making: cognitive strategies and detection of bias, *Acad Emerg Med* **9** (2002), 1184-1204.

[8]   P. Croskerry and D. Sinclair, Emergency medicine: A practice prone to error?, *CJEM* **3** (2001), 271-276.

[9]   A. Greig, J. Ryan, and E. Glucksman, How good are doctors at estimating children's weight?, *J Accid Emerg Med* **14** (1997), 101-103.

[10]   J.D. Hoyle, A.T. Davis, K.K. Putman, J.A. Trytko, and W.D. Fales, Medication dosing errors in pediatric patients treated by emergency medical services, *Prehosp Emerg Care* **16** (2012), 59-66.

[11]   IBM, IBM SPSS Software, in, 2019.

[12]   H.Y. Kim, Statistical notes for clinical researchers: assessing normal distribution (2) using skewness and kurtosis, *Restor Dent Endod* **38** (2013), 52-54.

[13]   R. Luten, Error and time delay in pediatric trauma resuscitation: addressing the problem with color-coded resuscitation aids, *Surg Clin North Am* **82** (2002), 303-314, vi.

[14]   R. Luten, R.L. Wears, J. Broselow, P. Croskerry, M.M. Joseph, and K. Frush, Managing the unique size-related issues of pediatric resuscitation: reducing cognitive load with resuscitation aids, *Acad Emerg Med* **9** (2002), 840-847.

[15]   Ministry of Health, *Emergency Department Use 2014/15*, Minsitry of Health, Wellington, 2016.

[16]   Ministry of Health, Sample Design from 2015/16: New Zealand Health Survey, in, 2016.

[17]   New Zealand Resuscitation Council, Flowchart for the sequential management of life-threatening dysrhythmias in infants and children, in: *ANZCOR Guideline 12.3*, New Zealand Resuscitation Council, 2016.

[18]   S. Riley, *Mindful design: how and why to make design decisions for the good of those using your product*, Apress, 2019.

[19]   E. Rush, P. Reed, S. McLennan, T. Coppinger, D. Simmons, and D. Graham, A school-based obesity control programme: Project Energize. Two-year outcomes, *Br J Nutr* **107** (2012), 581-587.

[20]   E.C. Rush, L.D. Plank, P.S. Davies, P. Watson, and C.R. Wall, Body composition and physical activity in New Zealand Maori, Pacific and European children aged 5-14 years, *Br J Nutr* **90** (2003), 1133-1139.

[21]   M. Samuels, S. Wieteska, M. Samuels, and Advanced Life Support Group (Manchester England), *Advanced paediatric life support : a practical approach*.

[22]   T. Smith, *Clinical proceedings and guidelines*, St John New Zealand, 2016.

[23]   Statistics New Zealand, New Zealand health survey dataset (2012 - 2016), in, 2016.

[24]   L. Theron, A. Adams, K. Jansen, and E. Robinson, Emergency weight estimation in Pacific Island and Maori children who are large-for-age, *Emerg Med Australas* **17** (2005), 238-243.

[25]   O. Wetzel, A.R. Schmidt, M. Seiler, D. Scaramuzza, B. Seifert, D.R. Spahn, and P. Stein, A smartphone application to determine body length for body weight estimation in children: a prospective clinical trial, *J Clin Monit Comput* **32** (2018), 571-578.