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ORIGINAL RESEARCH

A smartphone application to determine body length for body weight estimation in children: a prospective clinical trial

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Abstract The aim of this study was to test the feasibility and accuracy of a smartphone application to measure the body length of children using the integrated camera and to evaluate the subsequent weight estimates. A prospective clinical trial of children aged 0–<13 years admitted to the emergency department of the University Children's Hospital Zurich. The primary outcome was to validate the length measurement by the smartphone application «Optisizer». The secondary outcome was to correlate the virtually calculated ordinal categories based on the length measured by the app to the categories based on the real length. The third and independent outcome was the comparison of the different weight estimations by physicians, nurses, parents and the app. For all 627 children, the Bland Altman analysis showed a bias of −0.1% (95% CI −0.3–0.2%) comparing real length and length measured by the app. Ordinal categories of real length were in excellent agreement with categories virtually calculated based upon app length (kappa = 0.83, 95% CI 0.79–0.86). Children's real weight was underestimated by physicians (−3.3, 95% CI −4.4 to −2.2%, $p < 0.001$), nurses (−2.6, 95% CI −3.8 to −1.5%, $p < 0.001$) and parents (−1.3, 95% CI −1.9 to −0.6%, $p < 0.001$) but overestimated by categories based upon app length (1.6, 95% CI 0.3–2.8%, $p = 0.02$) and categories based upon real length (2.3, 95% CI 1.1–3.5%, $p < 0.001$). Absolute weight differences were lowest, if estimated by the parents (5.4, 95% CI 4.9–5.9%, $p < 0.001$). This study showed the accuracy of length measurement of children by a smartphone application: body length determined by the smartphone application is in good agreement with the real patient length. Ordinal length categories derived from app-measured length are in excellent agreement with the ordinal length categories based upon the real patient length. The body weight estimations based upon length corresponded to known data and limitations. Precision of body weight estimations by paediatric physicians and nurses were comparable and not different to length based estimations. In this non-emergency setting, parental weight estimation was significantly better than all other means of estimation

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(paediatric physicians and nurses, length based estimations) in terms of precision and absolute difference.

Keywords Body weight estimations · Smartphone application · Paediatric emergency · Emergency ruler

1 Introduction

Patient weight is one of the most important parameters in paediatric emergency situations, as most medication doses are weight based [1, 2]. However, in paediatric emergencies, the patient's weight is often unknown. Apart from patient weight, adequate size of emergency equipment (e.g. the endotracheal tube size and depth of insertion) correlates with patient body length or indirectly with patient age [2–4].

For this reason multiple length based emergency tapes have been developed [5–7], allowing body length based estimation of body weight and suggestion of drug dosing to reduce medication errors in emergency settings. Especially in paediatric patients there is a higher risk of administering an improperly dosed drug [8]. A calculation error does not necessarily mean clinical harm, but medication errors in children often include a factor of 10 or more [9–11] which can be fatal as shown in the case of adrenaline dosing [12]. The emergency tapes or rulers are physically positioned parallel to the child and depending on child's length, an ordinal length category is determined, which consecutively recommends medication dosing, equipment size and a child's weight range accordingly.

Available smartphone applications do not yet allow direct measurement of age, length or weight in conjunction with a dosing recommendation. This led to the idea of creating a smartphone application (Optisizer App) to measure the body length of children using the integrated camera.

The aim of this prospective clinical study was firstly to evaluate the accuracy of this smartphone application for body length measurement and secondly to investigate if the app can be used for body weight estimation based upon available ordinal length categories of known emergency tapes.

2 Methods

This prospective single centre observational study was approved by local ethics committee (Kantonale Ethikkommission Zurich: EKZH 94-2015/2016-00271, Chairperson Dr. Peter Kleist) and registered at clinicaltrials.gov (NCT02805192). The study was performed in the emergency department of the University Children's Hospital Zurich between February and July 2016.

2.1 Smartphone and "Optisizer App"

The Optisizer App was programmed by the Robotics and Perception Group (University of Zurich, Zurich, Switzerland) and is written in Java to access the Apriltag library [13], from which a 20×20 cm sized tag was chosen and used as a reference for length determination of objects (e.g. patient). This tag is positioned at the same level next to the patient. The Optisizer App was installed on an Android based Cat S 50 (Bullit Group, Reading, United Kingdom) with an integrated 8 mega pixel camera. The pictures taken by the camera have a size of 1920×1080 pixels. The user is required to take a picture which includes the patient and the tag. Two points (the head and the heels) have to be marked, and the distance is then computed by the app (Fig. 1). The software uses the tag to estimate the position and orientation of the tag with respect to the smartphone camera. With this information, the software projects the two points selected by the user onto the tag reference plane and then estimates the distance between these. In order to ensure that the user correctly picks the points of measurement, the app provides a zoomed-in version of the image to define the measurement position. The time required is well below 30 s. The picture taking is comparable to any other picture taking with a modern smartphone camera. Calculation of medication dose or equipment can be customized to the organization's equipment and will be performed automatically. The automated calculation of medication and equipment with all its implications is not part of this study.

2.1.1 Emergency tapes

The Broselow Tape (Vital Signs, Inc., Totowa, NJ, USA) is one of the most used and best known and popular tapes, developed in 1988 and updated using data from The National Health and Nutrition Examination Survey (NHANES). The tape is valid from 46 to 143 cm and categorizes the developing child [5, 14] into 26 weight categories and suggests drug dosing based on 11 ordinal length categories.

The Kindersicher tape utilizes the same ordinal length categories as the Broselow tape version 2011 [14]. It is adapted to suit differences in local or regional medication names or habits. Kindersicher Germany (Heide, Germany) and Kindersicher Switzerland (Affoltern am Albis, Switzerland) use the same ordinal length categories as the Broselow tape but advise use of medication and equipment for the German speaking region. The length range is 47–143.6 cm, which includes children with the weight of 3–36 kg. The ordinal categories (depending on length interval) have a colour code, a minimum and maximum weight approximation and a mean weight (used for dose calculations). The ordinal length categories are depicted in Table 1. The category dependent information and

Fig. 1 Example pictures of the "Optisizer" App. At first, a picture is taken with tag and child. The tag is recognized by the app and the body length has to be manually tagged at the upper limit (*middle picture*) of the head and, in a second step, at the heels (*last picture*). Consecutively a length is calculated by the app (valid size in the *last picture*)

Table 1 Ordinal length categories of Kindersicher

Body length (min/max) (kg)	Colour code	Weight range (min/max) (kg)	Mean weight (kg)
47–52	Grey	n/a	3
52–55	Grey	n/a	4
55–59	Grey	n/a	5
59–70	Pink	6/8	6.5
70–74	Red	8/9	8.5
74–84	Purple	10/11	10.5
84–95.5	Yellow	12/14	13
95.5–108	White	15/18	16.5
108–121.5	Blue	19/23	21
121.5–131	Orange	24/29	26.5
131–143.5	Green	30/36	33
>143.5	n/a		

From body length, a weight range and a mean weight (for dosage calculations) is determined. The colour coded 12 categories include patients from 47 to 143.5 cm

n/a not available

dosing recommendation can be checked in a separate booklet which is adapted to medication used in Switzerland and central Europe.

2.1.2 Inclusion criteria

Children aged 0–<13 years admitted to the emergency department of the University Children's Hospital Zurich of age. Per age (year) category, 45 children were included.

2.1.3 Exclusion criteria

Critically ill children, uncooperative children or denial of informed parental consent.

2.1.4 Endpoints

The primary outcome of the present study was to validate the smartphone application «Optisizer» by comparison of the length measured by the app by the real length measured with a validated stadiometer.

The secondary outcome was to correlate the virtually calculated Kindersicher ordinal categories based on the length measured by the app to the Kindersicher ordinal categories based on the real length.

The third and independent outcome was the comparison of the different weight estimations between physicians, nurses, parents and by the app (via Kindersicher ordinal categories).

2.1.5 Setting

After obtaining informed parental consent, independent and undisclosed weight estimations were performed in the following order: the nurse, the parents and the treating physician. The patient's body length was then measured with the Optisizer App. For children able to stand upright, the picture was taken with the child standing against the wall, so the child was always at the same level as the used tag (Fig. 1). For new-born and small children (0–2 years) the picture was taken with the child lying in supine position. If necessary, a second person held the legs straight. The head of the patient needed to be horizontal, to facilitate a horizontal line from the inferior margin of the margo supraorbitalis to the meatus acusticus externus [15]. The tag used was 20×20 cm, at the same level as the child, just beside their body.

The Optisizer App was always used by the same study staff person (OW) for all pictures. The body length was then manually tagged at the upper limit of the head and the heels (Fig. 1). The length and respective Kindersicher ordinal length category was virtually calculated consecutively. Afterwards, the children's length was measured with a validated stadiometer from Seca (Seca GmbH, Hamburg, Germany) or a hanged roll band from Seca. The weight was measured barefoot and in light underwear only. Diapers had to be dry and their weight was subtracted. The used scales were Spyder 2–35 A (Mettler Toledo GmbH, Albstadt, Germany, max 35 kg, tolerance 0.01 g) for children up to the age of 2 years (accuracy of 0.01 kg) and scales (Beurer GmbH, Ulm, Germany, Art. No. 756.41) for children >2 years of age (accuracy 0.1 kg).

2.1.6 Variables and data collection

Patient demographic data (length, weight, age in years and gender) in addition to nurse and physician data (experience in paediatric treatment in years, board specialisation) were recorded for every measurement. The length measured by the Optisizer App (in cm) and the virtually calculated Kindersicher ordinal length category, the weight (in kg) estimated by the parents, nurse and treating physician were noted. The (real) weight and length was measured, collected and transferred into a spreadsheet (Microsoft Windows Excel 2016, Microsoft Corporation, Redmond, WA, USA). The data was crosschecked by two individual persons. Differences between the estimated, calculated and measured weight were calculated.

2.1.7 Statistical analysis

Data was presented as mean ± standard deviation and (minimum–maximum). The boxplot depicted the median and the interquartile range. T test was used to calculate mean differences and 95% confidence intervals (CI). Paired samples t test was used to calculate mean absolute differences and 95% CI. A p value of <0.01 was considered significant. Agreement, bias and limits of agreement between two measurement methods and the 95% confidence intervals were determined according to Bland and Altman [16]: (App measured length—real length)/real length × 100. Cohen's kappa was used to measure inter-rater agreement for categorical items. Statistical data was analysed with IBM SPSS Statistics (version 22, IBM Corporation, Armonk, NY, USA).

3 Results

3.1 Epidemiology

Data collection was started in February 2016. In total, 627 children were included in this study and 57% were male. Mean age was 5.9 ± 3.7 years. Mean measured values were a length of 117.9 ± 25.4 (62–172) cm, a weight of 25.4 ± 13.2 (5.9–80.1) kg and BMI of 17.0 ± 2.8 (12.0–30.9) kg/m^2.

A total of 35 physicians and 32 nurses estimated the children's weight. Mean physician experience was 5.3 ± 5.4 years and nurse experience was 12.7 ± 11.9 years. Nurses estimated 19.6 ± 31.8 times and physicians 17.9 ± 21 times.

3.2 App measured length and real length

For all 627 measurements, the Bland Altman analysis showed a bias of −0.1% (95% CI −0.3–0.2%) with a lower limit of agreement of −5.5% (95% CI −5.9 to −5.1%) and an upper limit of agreement of 5.4% (95% CI 5.0–5.8%). If only 509 measurements <143.6 cm were included (to fit the Kindersicher ordinal length categories) Bland Altman analysis shows a bias of −0.6% (95% CI −0.8 to −0.4%) with a lower limit of agreement of −5.8% (95% CI −6.2 to −5.4%) and an upper limit of agreement of 4.6% (95% CI 4.2–5.0%, Fig. 2).

3.3 Ordinal length categories (Kindersicher tape) derived from app and real length

The Kindersicher ordinal categories based on real children's length were in excellent agreement with the categories calculated virtually with the app (kappa = 0.83, 95% CI 0.79–0.86, Table 2). The estimations differed by one (the next category) only. The estimate of the children's weight category was correct in 55.2 ± 0.5%, if judged by Kindersicher ordinary category calculated virtually upon app length

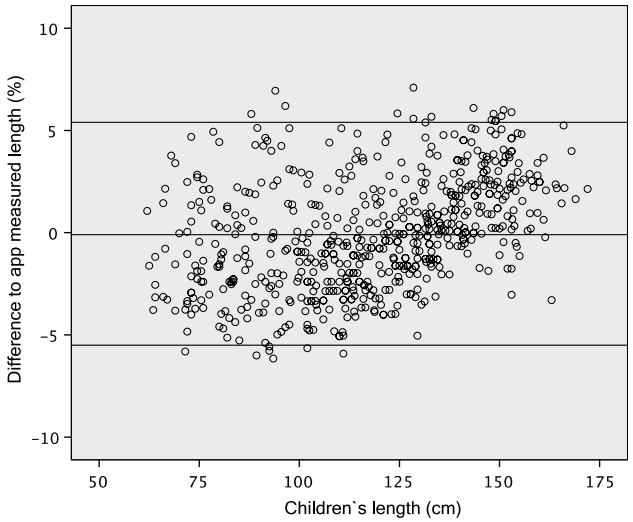

Fig. 2 Agreement of app measured length with real length. All 627 measurements are displayed. *X-axis* real children's length (cm); *Y-axis* difference between real children's length and app measured length (%). Bland Altman analysis showed a bias of −0.1% (*centre line*, 95% CI −0.3–0.2%) with a lower limit of agreement of −5.5% (*upper line*, 95% CI −5.9 to −5.1%) and an upper limit of agreement of 5.4% (*lower line*, 95% CI 5.0–5.8%)

and in 56.9 ± 0.5% (not different, p = 0.55) if judged by Kindersicher upon real children's length.

3.4 Relative differences of weight estimations

Children's weight was estimated by physicians, nurses, parents and by Kindersicher (by app length and real length). Differences per cent between estimated and real weight with mean differences and its 95% confidence intervals were calculated. The children's weight was underestimated (compared to real weight) by physicians (mean −3.3, 95% CI −4.4 to −2.2%, p < 0.001), nurses (mean −2.6%, 95% CI −3.8 to −1.5%, p < 0.001) and parents (mean −1.3%, 95% CI −1.9 to −0.6%, p < 0.001) but was estimated to be higher than the actual weight by Kindersicher, using the app length (mean 1.6%, 95% CI 0.3–2.8%, p = 0.02) and Kindersicher based upon real length (mean 2.3, 95% CI 1.1–3.5%, p < 0.001; Fig. 3).

3.5 Absolute differences of weight estimations

Absolute weight differences estimated by physicians (10.9, 95% CI 10.2–11.7%), nurses (11.3, 95% CI 10.5–12.0%), Kindersicher based upon app length (11.4, 95% CI 10.6–12.1%) and Kindersicher based upon real length (11.3, 95% CI 10.6–12.0%) were comparable and not different from each other (all p values > 0.15). If estimated by the parents, absolute weight differences were lowest and significantly better than all other estimations mentioned above (5.4, 95% CI 4.9–5.9%, p < 0.001).

Estimations were within 10% of the correct weight in 56.8% by physicians, in 54.7% by nurses, in 52.0% by Kindersicher based upon app length and 52.1% by Kindersicher based upon real length.

Table 2 Ordinal length categories

Ordinal length category by app (cm)	Ordinal length category upon real length (cm)												Total
	47–52	52–55	55–59	59–70	70–74	74–84	84–95.5	95.5–108	108–121.5	121.5–131	131–143.5	>143.5	
47–52	0	0	0	0	0	0	0	0	0	0	0	0	0
52–55	0	0	0	0	0	0	0	0	0	0	0	0	0
55–59	0	0	0	0	0	0	0	0	0	0	0	0	0
59–70	0	0	0	8	2	0	0	0	0	0	0	0	10
70–74	0	0	0	2	19	8	0	0	0	0	0	0	29
74–84	0	0	0	0	1	40	5	0	0	0	0	0	46
84–95.5	0	0	0	0	0	0	46	6	0	0	0	0	52
95.5–108	0	0	0	0	0	0	6	71	16	0	0	0	93
108–121.5	0	0	0	0	0	0	0	2	90	9	0	0	101
121.5–131	0	0	0	0	0	0	0	0	4	61	6	0	71
131–143.5	0	0	0	0	0	0	0	0	0	8	81	1	90
>143.5	0	0	0	0	0	0	0	0	0	0	18	117	135
Total	0	0	0	10	22	48	57	79	110	78	105	118	627

Ordinal length categories were determined upon app length (rows) and upon real length (columns) according to the Kindersicher categories (Table 1). Excellent agreement of the categories calculated virtually upon app length with the categories calculated upon real length (kappa = 0.83, 95% CI 0.79–0.86)

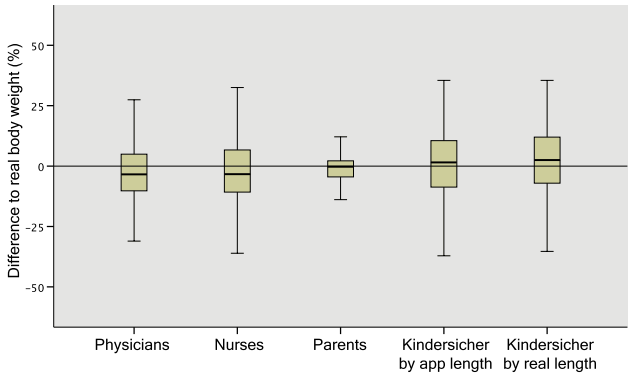

Fig. 3 Deviation between different estimations and real body weight (%). Children's real weight was underestimated by physicians (−3.3, 95% CI −4.4 to −2.2%, $p<0.001$), nurses (−2.6, 95% CI −3.8 to −1.5%, $p<0.001$) and parents (−1.3, 95% CI −1.9 to −0.6%, $p<0.001$) but overestimated by Kindersicher, based upon app length (1.6, 95% CI 0.3–2.8%, $p=0.02$) and Kindersicher based upon real length (2.3, 95% CI 1.1–3.5%, $p<0.001$)

4 Discussion

This study investigated the accuracy of a smartphone application for body length determination and based on this length, the possibility of body weight estimation. The main findings are: (i) a good agreement of body length determined by the smartphone application, with the real patient length, (ii) the Kindersicher ordinal length categories based upon app length are in excellent agreement with the Kindersicher ordinal length categories based on the real patient length, (iii) there were no outliers outside the subsequent Kindersicher weight category, (iv) precision of weight estimation differs according to the group of people estimating, with parents giving the most precise weight estimation with the highest precision and lowest absolute difference. Physicians and nurses working in a paediatric emergency department provide comparable weight estimations to those based upon Kindersicher ordinal categories upon real length as well as app-determined length.

Multiple studies have investigated the accuracy of emergency tapes with regard to weight estimation and found an accurate agreement in 55–65% of the measured children [2, 17–19]. This percentage did not change over time and is probably the limit for a fixed and not BMI or ethnics adjusted weight estimation based on plain children length [20]. Published weight estimations by parents (within 10% of real weight) were precise and ranged from 73% [21] to 85% [22]. Medical staff (physicians and nurses) were reported to be less precise with 43% [19] and 71% (within 15%) [23]. The weight of obese children tends to be generally underestimated by the parents in a meta analysis by Lundahl et al.[24]. The weight of obese individuals is clearly not detected by length measurement and therefore the weight is underestimated [1]. This may lead to under-dosing of drugs with a high volume of distribution or toxicity in underweight children [25–27]. If the investigation only includes children from the 10th to the 75th weight percentile, three quarters of the investigated population's weight are judged correctly [2]. An evolution of the current app software may acquire the body shape of an individual and calculate its volume or weight respectively. This may enhance precision of the estimations. We report the relative differences, because this value depicts, if weight is generally over or underestimated by certain means (or persons) of estimation. These relative differences in regard to real weight are low. This may be because over and underestimation self-balances the overall value.

The absolute difference of weight estimation, which may lead to incorrect dosing of medication by the same percentage, was therefore calculated and displayed.

The use of ordinal categories with a length (and consecutive weight) range introduce a certain vagueness and approximation of the estimations. The Kindersicher ordinal category determined virtually by the app was in excellence agreement with the ordinal category derived from real children length. As categories change from 1 mm to the next and imprecise measurement are inherent in both methods, a certain category variance must be accepted.

Different formula and tapes were not compared in this study intentionally. The difference between these methods and their individual imprecision are known [1, 2]. The derived estimations often do not consider the individual child's features like gender, ethnicity, BMI and medical condition [1, 28]. The more sophisticated methods with additional information may increase estimation precision [29]. With length based algorithms to calculate weight, doses and equipment the potential lethal factor ten (or more) errors can be ruled out to a large extent [9–11]. In contrast to medication, medical equipment like endotracheal tubes and endotracheal tube depth of intubation may correlate better to actual patient length than to age and weight [3, 30, 31]. Emergency tapes or rulers are limited to the medication and equipment printed on the ruler or the additional sheets. Any person in the team may make the measurement with the smartphone app, and the automated calculations are available directly after the measurement. The secondary output of the app (medication, equipment) may be customized to the emergency organization, which is not per se feasible with a tape, and thus gives app measurement an advantage. The secondary output was not part of the study design and therefore not analysed in this study.

This is the first study to present data comparing parental, paediatric nurse and physician weight estimations and length based weight estimations in a prospective way with more than 600 children.

4.1 Limitations

This prospective single centre study validated the precision of a smartphone app to measure the length of children. The app measurements were performed by only one skilled study staff person, so the generalisability of the app performance in the hand of a less trained person is not yet known. The results may be different in varying epidemiologic children compositions. Furthermore, as no individuals for the lower length range of the Kindersicher (46–62 cm) could be recruited, the accuracy of the app in this range was not investigated. Children older than 2 years of age were measured in an upright standing position as this was a proof of principle study. One upcoming version of the app is even able to measure children with legs not lying straight, a measurement which would be less easily feasible with a tape.

4.2 Outlook

The app version investigated in this study necessitates a tag at the same level as the child to calculate its length and only one straight measurement was possible. A new version will be available, which allows to insert plane angles to measure children not lying flat, for example with their knees bent. Tag size may be chosen to be significantly smaller with current high-resolution smartphones. Optionally the tag may be fixed to a stretcher or other rescue equipment. Further smartphone technology with distance meters or multiple cameras may calculate distances without a referring object like the tag.

5 Conclusion

This study showed the accuracy of length measurement of children by a smartphone application: body length determined by the smartphone application is in good agreement with the real patient length. Ordinal length categories derived from app measured length are in excellent agreement with the ordinal length categories based upon the real patient length. The body weight estimations upon length corresponded to known data and limitations.

Precision of body weight estimations by paediatric physicians and nurses were comparable and not different to length based estimations.

In this non-emergency setting, parental weight estimation was significantly better than all other means of estimation (paediatric physicians and nurses, length based estimations) in terms of precision and absolute difference.

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Author Contributions PS and OW they planned the study, acquired the data, performed the data analysis and wrote the manuscript. BS analysed the data, performed the statistical analyses and wrote the manuscript. DRS, ARS, MS and DS collected the data and wrote the manuscript. All authors read and approved the final manuscript.Funding This work was supported by departmental funds.

Compliance with ethical standards

Conflict of interest OW, MS, DS, BS and PS have no conflicts of interest. ARS developed a gender specific and habitus-adapted continuous-length based algorithm for weight and age rainting (CLAWAR) utilized in an electronic paediatric emergency ruler and calculator for drug dosage and recommendation of medical airway equipment. Patent (16184553.2-1657) pending. Patent rights belong to the University of Zurich, Switzerland. Dr. Spahn's academic department is/has been receiving grant support from the Swiss National Science Foundation, Berne, Switzerland, the Ministry of Health (Gesundheitsdirektion) of the Canton of Zurich, Switzerland for Highly Specialized Medicine, the Swiss Society of Anesthesiology and Reanimation (SGAR), Berne, Switzerland, the Swiss Foundation for Anesthesia Research, Zurich, Switzerland, Bundesprogramm Chancengleichheit, Berne, Switzerland, CSL Behring, Berne, Switzerland, Vifor SA, Villars-sur-Glâne, Switzerland. Dr. Spahn is the co-chair of the ABC-Trauma Faculty, managed by Physicians World Europe, Mannheim, Germany and sponsored by unrestricted educational grants from Novo Nordisk Health Care AG, Zurich, Switzerland, CSL Behring GmbH, Marburg, Germany and LFB Biomédicaments, Courtaboeuf Cedex, France. In the past 5 years, Dr. Spahn has received honoraria or travel support for consulting or lecturing from: Danube University of Krems, Austria, Abbott AG, Baar, Switzerland, AMGEN GmbH, Munich, Germany, AstraZeneca AG, Zug, Switzerland, Baxter AG, Volketswil, Switzerland, Baxter S.p.A., Roma, Italy, Bayer, Zürich, Switzerland and Berlin, Germany, B. Braun Melsungen AG, Melsungen, Germany, Boehringer Ingelheim (Schweiz) GmbH, Basel, Switzerland, Bristol-Myers-Squibb, Rueil-Malmaison Cedex, France and Baar, Switzerland, CSL Behring GmbH, Hattersheim am Main, Germany and Berne, Switzerland, Curacyte AG, Munich, Germany, Daiichi Sankyo (Schweiz) AG, Thalwil, Switzerland, Ethicon Biosurgery, Sommerville, New Jersey, USA, Fresenius SE, Bad Homburg v.d.H., Germany, Galenica AG, Bern, Switzerland (including Vifor SA, Villars-sur-Glâne, Switzerland), GlaxoSmithKline GmbH & Co. KG, Hamburg, Germany, Haemonetics, Braintree, MA, USA, Janssen-Cilag, Baar, Switzerland and Beerse, Belgium, LFB Biomédicaments, Courtaboeuf Cedex, France, Merck Sharp & Dohme AG, Luzern, Switzerland, Novo Nordisk A/S, Bagsvärd, Denmark, Octapharma AG, Lachen, Switzerland, Organon AG, Pfäffikon/SZ, Switzerland, PAION Deutschland GmbH, Aachen, Germany, Pharmacosmos A/S, Holbaek, Denmark, Photonics Healthcare B.V., Utrecht, Netherlands, ratiopharm Arzneimittel Vertriebs-GmbH, Vienna, Austria, Roche, Reinach, Switzerland, Sarstedt AG & Co., Sevelen, Switzerland and Nümbrecht, Germany, Schering-Plough International, Inc., Kenilworth, New Jersey, USA, Tem International

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Ethical approval This prospective single centre observational study was approved by local ethics committee (Kantonale Ethikkommission Zurich: EKZH 94-2015/2016-00271, Chairperson Dr. Peter Kleist) and registered at clinicaltrials.gov (NCT02805192). All necessary written informed consent from any patients involved in the study, including consent to participate in the study was obtained. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

1. Young KD, Korotzer NC. Weight Estimation Methods in Children: A Systematic Review. Ann Emerg Med. 2016;68(441–451):e10. doi:10.1016/j.annemergmed.2016.02.043.
2. Schmidt AR, Haas T, Buehler KP, Ruetzler K, Weiss M, Schmitz A (2015) Comparison of Broselow® tape and pediatric emergency ruler. Notfall Rettungsmed. doi:10.1007/s10049-015-0070-4.
3. Kemper M, Dullenkopf A, Schmidt AR, Gerber A, Weiss M. Nasotracheal intubation depth in paediatric patients. Br J Anaesth. 2014;113:840–6. doi:10.1093/bja/aeu229.
4. Weiss M, Knirsch W, Kretschmar O, Dullenkopf A, Tomaske M, Balmer C, Stutz K, Gerber AC, Berger F. Tracheal tube-tip displacement in children during head-neck movement–a radiological assessment. Br J Anaesth. 2006;96:486–91. doi:10.1093/bja/ael014.
5. Luten RC, Wears RL, Broselow J, Zaritsky A, Barnett TM, Lee T, Bailey A, Vally R, Brown R, Rosenthal B. Length-based endotracheal tube and emergency equipment in pediatrics. Ann Emerg Med. 1992;21:900–4.
6. Lowe CG, Campwala RT, Ziv N, Wang VJ. The Broselow and Handtevy Resuscitation Tapes: A Comparison of the Performance of Pediatric Weight Prediction. Prehosp Disaster Med. 2016;31:364–75. doi:10.1017/S1049023X16000455.
7. Luscombe MD, Owens BD, Burke D. Weight estimation in paediatrics: a comparison of the APLS formula and the formula 'Weight = 3(age) + 7'. Emerg Med J. 2011;28:590–3. doi:10.1136/emj.2009.087288.
8. Ghaleb MA, Barber N, Franklin BD, Wong ICK. The incidence and nature of prescribing and medication administration errors in paediatric inpatients. Arch Dis Child. 2010;95:113–8. doi:10.1136/adc.2009.158485.
9. Ghaleb MA, Barber N, Franklin BD, Yeung VWS, Khaki ZF, Wong ICK. Systematic review of medication errors in pediatric patients. Ann Pharmacother. 2006;40:1766–76. doi:10.1345/aph.1G717.
10. Rowe C, Koren T, Koren G. Errors by paediatric residents in calculating drug doses. Arch Dis Child. 1998;79:56–8.
11. Kaufmann J, Laschat M, Wappler F. Medication errors in pediatric emergencies: a systematic analysis. Dtsch Arztebl Int. 2012;109:609–16. doi:10.3238/arztebl.2012.0609.
12. Perondi MBM, Reis AG, Paiva EF, Nadkarni VM, Berg RA. A comparison of high-dose and standard-dose epinephrine in children with cardiac arrest. N Engl J Med. 2004;350:1722–30. doi:10.1056/NEJMoa032440.
13. Olson E (2011) AprilTag: a robust and flexible visual fiducial system. IEEE inter-national conference on robotics and automation ICRA 2011, pp 3400–3407. IEEE:New York.
14. Lubitz DS, Seidel JS, Chameides L, Luten RC, Zaritsky AL, Campbell FW. A rapid method for estimating weight and resuscitation drug dosages from length in the pediatric age group. Ann Emerg Med. 1988;17:576–81.
15. Prader A, Largo RH, Molinari L, Issler C. Physical growth of Swiss children from birth to 20 years of age. First Zurich longitudinal study of growth and development. Helv Paediatr Acta Suppl. 1989;52:1–125.
16. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res. 1999;8:135–60. doi:10.1177/096228029900800204.
17. Hofer CK, Ganter M, Tucci M, Klaghofer R, Zollinger A. How reliable is length-based determination of body weight and tracheal tube size in the paediatric age group? The Broselow tape reconsidered. Br J Anaesth. 2002;88:283–5.
18. Nieman CT, Manacci CF, Super DM, Mancuso C, Fallon WF. Use of the Broselow tape may result in the under resuscitation of children. Acad Emerg Med. 2006;13:1011–9. doi:10.1197/j.aem.2006.06.042.
19. Rosenberg M, Greenberger S, Rawal A, Latimer-Pierson J, Thundiyil J. Comparison of Broselow tape measurements versus physician estimations of pediatric weights. Am J Emerg Med. 2011;29:482–8. doi:10.1016/j.ajem.2009.12.002.
20. So TY, Farrington E, Absher RK. Evaluation of the accuracy of different methods used to estimate weights in the pediatric population. Pediatrics. 2009;123:e1045–e51. doi:10.1542/peds.2008-1968.
21. Goldman RD, Buskin S, Augarten A. Parental estimates of their child's weight: accurate for resuscitation drug doses. Pediatr Emerg Care. 1999;15:19–21.
22. Trakulsrichai S, Boonsri C, Chatchaipun P, Chunharas A. Accuracy of three methods used for Thai children's body weight estimation. J Med Assoc Thai. 2012;95:1194–9.
23. Harris M, Patterson J, Morse J. Doctors, nurses, and parents are equally poor at estimating pediatric weights. Pediatr Emerg Care. 1999;15:17–8.
24. Lundahl A, Kidwell KM, Nelson TD. Parental underestimates of child weight: a meta-analysis. Pediatrics. 2014;133:e689–e703. doi:10.1542/peds.2013-2690.
25. Luten R, Zaritsky A. The sophistication of simplicity...optimizing emergency dosing. Acad Emerg Med. 2008;15:461–5. doi:10.1111/j.1553-2712.2008.00107.x.
26. Brodsky JB, Foster PE. Succinylcholine and morbid obesity. Obes Surg. 2003;13:138–9. doi:10.1381/096089203321136755.
27. Carasco CF, Fletcher P, Maconochie I. Review of commonly used age-based weight estimates for paediatric drug dosing in relation to the pharmacokinetic properties of resuscitation drugs. Br J Clin Pharmacol. 2016;81:849–56. doi:10.1111/bcp.12876.
28. Ramarajan N, Krishnamoorthi R, Strehlow M, Quinn J, Mahadevan SV. Internationalizing the Broselow tape: how reliable is weight estimation in Indian children. Acad Emerg Med. 2008;15:431–6. doi:10.1111/j.1553-2712.2008.00081.x.
29. Wells M, Coovadia A, Kramer E, Goldstein L. The PAWPER tape: A new concept tape-based device that increases the accuracy of weight estimation in children through the inclusion of a modifier based on body habitus. Resuscitation. 2013;84:227–32. doi:10.1016/j.resuscitation.2012.05.028.
30. KIM EJ, KIM SY, KIM WO, KIM H, KIL HK. Ultrasound measurement of subglottic diameter and an empirical formula for proper endotracheal tube fitting in children. Acta Anaesthesiol Scand. 2013;57:1124–30. doi:10.1111/aas.12167.
31. Weiss M, Dullenkopf A, Bottcher S, Schmitz A, Stutz K, Gysin C, Gerber AC. Clinical evaluation of cuff and tube tip position in a newly designed paediatric preformed oral cuffed tracheal tube. Br J Anaesth. 2006;97:695–700. doi:10.1093/bja/ael247.