Original article

Challenges in body composition assessment using air-displacement plethysmography by BOD POD in pediatric and young adult patients

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SUMMARY

Background & aims: Air-Displacement-Plethysmography (ADP) by BOD POD is widely used for body fat assessment in children. Although validated in healthy subjects, studies about use in pediatric patients are lacking. We evaluated user experience and usability of ADP measurements with the BOD POD system in healthy children and pediatric and young adult patients.
Methods: Using the experiences of seven cohort studies, which included healthy children and patients aged 2–22 years, we retrospectively evaluated the user experience with the User Experience Questionnaire (UEQ) (n = 13) and interviews (n = 7). Technical performance was studied using the quality control data collected by the ADP-system.
Results: From 2016 to 2022, 1606 measurements were scheduled. BOD POD was mostly rated 'user-friendly', with a generally neutral evaluation on all scales of the UEQ. However, questionable reliability and validity of the results were frequently (86%) reported. We found a high technical failure-rate of the device, predominantly in stability (17%) and accuracy of the measurement (12%), especially in the 'pediatric option' for children aged <6 years. Measurement failure-rate was 38%, mostly due to subject's fear or device failure, especially in young and lean children, and in children with physical and/or intellectual disabilities.
Conclusion: We conclude that ADP by BOD POD in children and young adults is non-invasive and user-friendly. However, in specific pediatric populations, BOD POD has several limitations and high (technical) failure-rates, especially in young children with aberrant body composition. We recommend caution

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when interpreting body composition results of pediatric patients as assessed with BOD POD using the current default settings.

Abbreviations

ADP	Air Displacement Plethysmography
BPD	bronchopulmonary dysplasia
CGG	Centrum Gezond Gewicht
Dffm	fat free mass density
Dfm	fat mass density
DXA	Dual Energy X-ray absorptiometry
FM%	fat mass percentage
FFM	fat free mass
FM	fat mass
GA	gestational age
IBD	Inflammatory bowel disease
i.e.	in example
N	number
NA	not applicable
QC	quality control
SAA	Surface Area Artifact
SD	standard deviation
UEQ	User Experience Questionnaire

1. Introduction

Measurement of body fat mass, both in healthy and sick children, is of growing interest in pediatric research, as (chronic) disease status is known to affect body composition [1]. Multiple techniques to determine body composition are available. Air-displacement plethysmography (ADP) is widely used in infants (≤6 months old and/or ≤8 kg) using PEA POD [2,3], and in children (≥6 years) and adults using BOD POD® (BOD POD) [4], because it is non-invasive and user-friendly. Since the development of specialized hardware, including a pediatric seat and software for younger children in 2011, BOD POD can also be used in children aged ≥2 years and ≥12 kg [5].

ADP uses a 2-compartment technique and determines fat mass percentage (FM%) by measuring body volume in a secluded space, utilizing the inverse pressure-volume relation [4]. Other outcomes include absolute fat mass, fat free mass and body density. BOD POD could, in theory, be used longitudinally from age 2 years onwards, as it can be used in participants weighting 12−150 kg [4,6]. However, the use of BOD POD has several limitations. ADP measurements are influenced by movement and crying [5,6], which potentially makes its use less useable in young children and specific patient groups, e.g. children with intellectual disabilities. In fact, especially in young children with an aberrant body composition, such as preterm born children, we noticed that ADP results are often clinically questionable (e.g. extremely low values of fat mass percentage (FM%), <5%) years [7].

Recently, we reported body composition results from ADP in comparison with Dual Energy X-ray Absorptiometry (DXA) in children aged 3−5 years [7]. We found that the difference between techniques was larger in very preterm-born children compared to those born full-term, especially in very lean patients [7]. Although ADP has been validated against 4-compartment models in small samples of healthy children with normal

weight [5,8−10], literature about its use in pediatric and young adult patients is limited.

This study aimed to evaluate the user experience and usability of ADP measurements with the BOD POD system when used in several pediatric patient groups. We hypothesized that BOD POD may be less feasible to determine body composition in certain patients groups, such as children who were chronically ill, born very preterm, had obesity, or Angelman syndrome. In addition, we contemplate potential improvements to the BOD POD system for pediatric use.

2. Material & methods

2.1. Study populations

This study combined experiences and results of 7 observational studies running simultaneously between 2016 and 2022 at the Erasmus MC - Sophia Children's hospital in Rotterdam, The Netherlands [7,11−14]. The cohorts, which varied in size, included either healthy or (chronically) ill children 2−22 years of (corrected) age, as summarized in Table 1. A comprehensive overview of the study populations is available in the supplementary material. All studies were approved by the Medical Ethics Committee of the Erasmus Medical Center and participants gave written informed consent before participation.

2.2. Data collection

2.2.1. User experience evaluation

In September 2022, we approached all participating research groups that had used BOD POD. Researchers, consisting of physicians, nurses and dieticians retrospectively filled out a digital Dutch version of the User Experience Questionnaire (UEQ), that can be completed in 3−5 min [15]. The UEQ contains 6 scales with 26 items in total.

1. Attractiveness: Overall impression of the product. Do users like or dislike the product?
2. Perspicuity: Is it easy to get familiar with the product? Is it easy to learn how to use the product?
3. Efficiency: Can users solve their tasks without unnecessary effort?
4. Dependability: Does the user feel in control of the interaction?
5. Stimulation: Is it exciting and motivating to use the product?
6. Novelty: Is the product innovative and creative? Does the product catch the interest of users [15]?

The UEQ measures both classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation). To cover a comprehensive impression of user experience and reduce central tendency bias, a seven−stage scale was used to rate each item from −3 (most negative) through 0 (neutral) to +3 (most positive) [16]. Furthermore, we asked 2 open-ended questions to the BOD POD researchers: "Based on your experience, what are the advantages and disadvantages of using BOD POD for pediatric and young adult patients?" and "Which findings are of interest in your specific patient population?" Also,

Table 1
Overview of cohort studies in Erasmus MC Sophia Children's Hospital using BOD POD.

Cohort			Participants				Measurements	
	Design	Period	Diagnosis	N	Age	Sex	Timing BOD POD measurement	FFM density model
Sophia Pluto	Prospective longitudinal cohort study	2019-current	Healthy full-term born (≥37 weeks GA)	1012	0–5 years	♂ = ♀	Longitudinal at age 3, 4 and 5 years	Lohman [18]
BOND	Prospective longitudinal cohort study	2017-current	Very preterm born (<30 weeks GA)	142	0–8 years	♂ = ♀	Longitudinal at age 2, 3 and 5.5 years CA	Lohman
CGG	Prospective observational study	2014-current	Pediatric obesity	146	0–18 years	~60%♀	Baseline (if age ≥2 years)	Lohman
TROMPET	Prospective longitudinal cohort study	2016–2022	Intestinal failure after intestinal surgery	79	0–18 years	♂ = ♀	Longitudinal annually from age 2 years	Lohman
ROSA	Prospective observational study	2021–2022	Angelman Syndrome	25	2–18 years	♂ = ♀	Once (if age ≥2 years)	Lohman
EXERCISE	Randomized crossover trial	2020–2022	I) Fontan circulation II) BPD III) Pompe disease IV) IBD	72	6–18 years	~40%♀	Baseline, after 12 and after 24 weeks of follow-up	Lohman
BRAVE	Prospective observational study	2018–2022	First-onset anorexia nervosa	79	12–22 years	100% ♀	Baseline and after 1 year follow-up	Brozek [19]

Summary of the included cohort studies. Abbreviations: BPD: Bronchopulmonary dysplasia, CGG: Centrum Gezond Gewicht, FFM: fat free mass, GA: gestational age, IBD: Inflammatory bowel disease, N = number.

we collected data about all measurement failures and system error notification from the electronic clinical data management platform and case report forms from each research group.

2.3. BOD POD measurements

Up to December 2022, 1606 measurements were planned since the BOD POD system was installed in a dedicated research room of the (Erasmus MC Sophia Children's) Hospital in August 2016. All seven research groups used the same BOD POD device (COSMED USA, Inc. Concord, CA) during the entire study period. Measurements were scheduled using a joint agenda and were performed by trained personnel, all conducted at least 20 measurements per person. The device was warmed up and calibrated daily, and used and maintained according to the supplier's manual [17].

The mandatory daily Quality Control process consists of 5 phases. 'Analyze Hardware' assesses the electronic system and transducers. 'Calibrate' and 'Check scale' calibrates and assesses the performance of the attached scale. 'Autorun' assesses the stability of the BOD POD system and its surroundings. The last 'Volume' phase aims to assess the accuracy and reliability of a predetermined dummy volume of 50 or 20 L, for the default or pediatric setting, respectively. The entire quality control process, including warming up takes up to 1,5 h.

According to the manufacturer's instructions, we used the special pediatric chair, the supplied 20 L calibration volume cylinder, and the specialized pediatric software (v5.4.6) in children <6 years of age. All research groups used the default Lohman density model [18], except for the research group that studied patients with anorexia nervosa, which used Brozek's density model for individuals who are very lean and individuals with obesity [19]. During measurements, children were accompanied by their parent(s), and wore tight-fitting underwear and a swimming cap covering all scalp hair. Children were instructed not to move during the measurement. The duration of one measurement with a very cooperative and instructable subject was circa 15 min. The test-retest reliability of the device was evaluated previously in a random small sample of 13 term-born children, aged 3–5 years. Intra-class-correlation-coefficients for fat mass (FM) (kg), fat mass

percentage (FM%) and fat free mass (FFM) (kg) for BOD POD were 0.980, 0.978, and 0.994, respectively [7].

The Quality Control (QC) file was extracted from the BOD POD device on November 21st 2022, according to the supplier's manual [17], with Database Version V-1.1.40.

2.4. Statistical analysis

User experience data was analyzed using the 'UEQ Data Analysis Tool Version 10' from the UEQ website [16]. Raw data were inserted in the provided Microsoft Excel sheet, which was used to calculate scale means, mean and standard deviation [16]. Answers to the open ended questions were standardized by one researcher (IvB) and analyzed. Chi Square Test was used for comparison of number of failures between quality control procedures using the 20 L (pediatric) versus 50 L (adult) volume dummies. A two-tailed p-value <0.05 was considered statistically significant. Analyses were
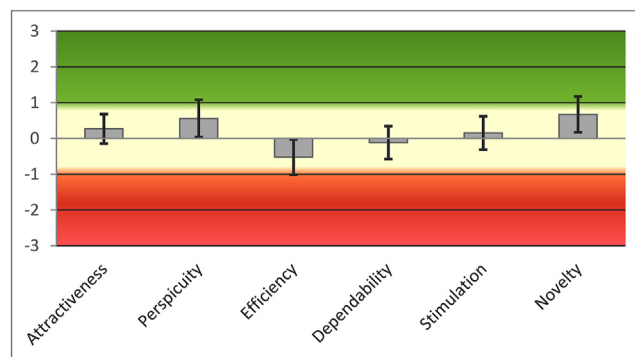

Fig. 1. Evaluation of BOD POD using UEQ Graphic display of the individual UEQ scales. Data is shown as mean and variance. 'Attractiveness': overall impression of the product. 'Perspicuity': mastering the product. 'Efficiency': efficiency of the product. 'Dependability': transparency of the product. 'Stimulation': excitement of use of the product. 'Novelty': innovation of the product. The range of the scales is between −3 (horribly bad) and +3 (extremely good). Values between −0.8 and 0.8 represent a more or less neutral evaluation of the corresponding scale, >0.8 represents a positive evaluation and < −0.8 represents a negative evaluation.

performed using SPSS v.25.0 (IBM SPSS Statistics, Armonk, NY) and Microsoft Excel 2016.

3. Results

3.1. User experience

From 2016 to 2022, 1606 BOD POD measurements were attempted. A total of 13 researchers filled out the UEQ, as shown in Fig. 1. All mean scores were in the range of −0.8 and 0.8, which represent a more or less neutral evaluation. Novelty and Perspicuity had the highest mean (SD) scores of 0.67 (0.92) and 0.56 (0.96), respectively. Efficiency and Dependability had the lowest mean (SD) scores, of −0.52 (0.91) and −0.12 (0.85), respectively.

Table 2
Reported advantages and disadvantages of BOD POD in healthy children and several pediatric and young adults patient groups.

Cohort	Reported advantages	Reported disadvantages
Healthy and term-born	No radiation User-friendly Possibility for the child to hold a toy	Time-consuming Refusal, movement and/or crying in young children Unreliable due to frequent QC failure and dependent of environmental factors Clinically questionable results, especially in children with very low or high weight
Very premature born	No radiation User-friendly Possibility for the child to hold a toy	Frequent invalid results in children with low weight Frequent clinically questionable results Refusal, movement and/or crying at age 2 and 3 years Dependent on environmental factors
Obesity	User-friendly	Time-consuming Frequent clinically questionable results Inability for young children with obesity to fit in Pediatric Option chair.
Intestinal failure	No radiation Possibility to calibrate a duplicate of the feeding tube, central venous catheter, enterostomy bag 'Easy to schedule' measurement	Time-consuming Expensive Unreliable due to frequent calibration failure and depending on environmental factors Frequent invalid results in youngest children (2 years) Gap in between PEA POD and BOD POD Fear or crying in young children No distinction between visceral and regional fat distribution No subdivision in bone and lean body mass
Angelman syndrome	User-friendly	Unreliable due to frequent QC failure Inability to use scale due to physical disability Frequent need for additional measurement needed due to movement artifacts Frequent invalid results in lean children and aged <8 years
Chronic illnesses (EXERCISE)	NA	Time-consuming Concerns about validity of longitudinal results
Anorexia Nervosa	User-friendly	Time-consuming Frequent invalid results in females with extreme underweight

Summary of reported (dis)advantages by 7 research physicians. Abbreviations: NA: not applicable, QC: quality control.

From each research group, the research physician filled out the open end questions in order to reflect on the experienced advantages and disadvantages of using BOD POD in their study population (Table 2). In summary, the most reported advantage was 'user-friendly for child and researcher' (71%), followed by 'possibility to correct measurement for (medical) devices (e.g. feeding tube, central venous catheter, enterostomy bag, tablet or stuffed animal)' (57%) and 'no radiation-use' (43%). The most reported disadvantage was 'concerns about reliability and validity', which was reported by all but one researcher (85%). Other disadvantages were 'time-consuming (warming-up, calibration, and measurement)' (71%), and 'frequent invalid results' (57%). The latter was most frequently reported in the cohorts with children who were born very-preterm, had anorexia, were chronically ill, and children with obesity. Furthermore, 'inability to use BOD POD according to user manual in specific patients or age groups' was reported in 43%, especially in the children who were chronically ill, born very preterm, had obesity, or Angelman syndrome.

3.2. Reliability of BOD POD measurements

3.2.1. BOD POD device

As one of the most reported disadvantages involved concerns about (technical) reliability, we analyzed the output of the Quality Control (QC) file to determine the failure rate during the mandatory daily Quality Control as a proxy for the technical reliability of the BOD POD device. As shown in Table 3, quality control failures occurred during 17% of the Autorun phases, indicating instability of the BOD POD device itself or its surroundings. During the Volume phase, failure was more common with the small Pediatric Option 20 L volume dummy (22%), as compared to the 50 L volume dummy (7%) (p < 0.001), which indicates more measurement inaccuracies when smaller volumes are used.

3.3. Measurements

In total, 1606 BOD POD measurements were planned from 2016 to 2022 (Table 4), of which 256 (16.9%) could not take place, due to technical or logistic difficulties. Eventually, 1006 (74.2%) measurements were successful (Table 4 and Fig. 2). Measurement failure was predominantly due to fear or resistance of the subject (13.6%), especially in young children or children with intellectual disability and the inability to use the BOD POD device according to its manual (3.1%), which was predominantly reported in young children with a total body weight below 12 kg, and in children aged <6 years with a body size that could not fit into the pediatric seat. Other explanations included physical and/or intellectual disabilities with an

Table 3
Technical reliability BOD POD.

Quality Control phase	N total	N Failure (%)	p-value
Analyze Hardware[a]	631	0	
Calibrate Scale[b]	628	11 (1.8%)	
Check Scale[c]	607	4 (0.7%)	
Autorun[d]	745	128 (17.2%)	
Volume[e]	445	97 (21.8%)	**<0.001**
20 L	452	32 (7.1%)	
50 L			

Data presented as count and percentage of total count of quality control processes and amount of technical failure. p-value for comparisons between small (20 L) and default (50 L) dummy volume using Chi-Square tests.
[a] Analyze Hardware to assess the electronic system and transducers.
[b] Calibrate Scale.
[c] Check Scale to assess the performance of the scale.
[d] Autorun to assess environmental and BOD POD stability.
[e] Volume to assess accuracy and reliability of BOD POD volume performance.

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Table 4
Measurement failure BOD POD.

	Cohort							TOTAL
	Healthy and term-born	**Very premature born**	**Obesity**	**Intestinal failure**	**Angelman syndrome**	Chronic illnesses (EXERCISE)	**Anorexia Nervosa**	
Planned measurements	**603**	**301**	**373**	**134**	**25**	**72**	**98**	**1606**
Logistic difficulties	80 (13.3%)	NA	51 (13.7%)	14 (10.4%)	NA	NA	NA	145 (9.0%)
No informed consent of subject/parents	13 (2.1%)	NA	2 (0.5%)	2 (1.5%)	NA	NA	4 (4%)	21 (1.3%)
Technical failure of the device	69 (11.4%)	17 (5.6%)	12 (3.2%)	1 (0.7%)	8 (32%)	2 (2.8%)	2 (2%)	111 (6.9%)
Attempted measurements	**441**	**284**	**308**	**117**	**21**	**70**	**92**	**1333**
Failure due to subject fear or resistance	143 (23.7%)	49 (16.3%)	8 (2.1%)	15 (11.2%)	4 (19.0%)	NA	NA	219 (13.6%)
Impossibility to use device according to manual	10 (1.7%)	14 (4.7%)	19 (5.1%)	6 (4.5%)	NA	NA	NA	49 (3.1%)
Missing data about failure	18 (3.0%)	1 (0.3%)	52 (13.9%)	NA	NA	NA	NA	71 (4.4%)
Successful measurements	**270 (44.8%)**	**220 (73.1%)**	**229 (61.4%)**	**97 (72.4%)**	**14 (56.0%)**	**70 (97.2%)**	**92 (93.9%)**	**1006 (62.6%)**

Data presented as count and percentage of causes of BOD POD measurement failure in comparison with the planned measurements. *Abbreviations*: NA: not applicable.

inability to stand independently on the attached scale or sit still in the secluded chamber.

4. Discussion

To our knowledge, this study is unique in evaluating user experience and performance of ADP by BOD POD in several pediatric and young adult patient populations with a large number of analyzed measurements. We found that our ADP users rated user experience more of less neural in general, with 'user-friendly' being the most frequently mentioned advantage in the open questions. However, concerns about the reliability and validity of the technique were frequently reported. We found a high technical failure-rate of BOD POD, predominantly in terms of stability of the device and accuracy of the measurements, especially when using the 'pediatric option' for children aged <6 years. Furthermore, we found high rate of failed measurements, mostly due to device failure or subject's fear, especially in young children and children with physical and/or intellectual disabilities.

4.1. BOD POD device

Generally, the BOD POD is perceived as non-invasive and user-friendly by our research physicians. This is in line with one small

Fig. 2. Successful BOD POD measurement rate displayed per study cohort. This figure illustrates successful measurements with the BODPOD system per study cohort. There was a high measurement failure-rate in study cohorts with children <6 years.

study performed in adolescents with eating disorders, which rated the BOD POD measurement as acceptable and comfortable [20]. Nevertheless, the device's operational stability and measurement accuracy have been called into question [21]. BOD POD measurements are highly dependent on air pressure and density, which are known to be influenced by several factors. Crying and movement affect the measurement's outcome because they influence the amplitude of pressure oscillations in the secluded space and subsequently the results [4,5]. We found these factors difficult to avoid, especially in young children (age ≤5 years) or children with behavioral problems or intellectual disabilities. Furthermore, air density is dependent on room temperature. According to the BOD POD's manual, room temperature should be stable between 21 and 27 °C and should not vary more than 0.5 °C during a test [17]. Although we succeeded in maintaining the room temperature between the requested limits, we speculate that temperature variation <0.5 °C was more difficult to control, especially because multiple people were present in the BOD POD room (i.e. researcher, child, parent(s). The requested small temperature range could partly explain the high failure rate in the 'QC Autorun phase' (17%), which tests stability of the device and its environment.

The BOD POD system was originally developed for subjects above 6 years of age. Due to the development of the specialized 'pediatric option' for younger children, BOD POD could also be used in children from age 2 years onwards [5]. However, we found that this 'pediatric option' has several limitations, especially in children with aberrant body composition. First, the custom pediatric seat does not fit young children with severe obesity. Also, we experienced that many children with chronic diseases had not reached 12 kg of body weight at age 2 years, due to impaired growth. According to the manual, BOD POD requires a minimum weight of 12 kg [17], therefore, low body weight in young (≤3 years of age) and preterm-born children might explain the high rate of failed measurements, due to the impossibility to use the device according to the manual in these groups. Furthermore, we found a high amount of clinically questionable results in these groups, for children who weighted 12–15 kg. We hypothesize that measurement precision could be impaired in children with a very low weight or small body volume, due to a large ratio of chamber volume to subject volume, which previously is reported as a challenge [4]. This could also explain the higher technical failure-rate using the pediatric volume (20 L) as compared to the 50 L volume, and the frequently reported clinically questionable results in young and/or very lean children. Lastly, BOD POD requires the subject to sit alone in a secluded space, which can cause separation anxiety, especially in young children or children with intellectual disabilities. This could explain the higher rate of measurement failure which we have found in these specific groups.
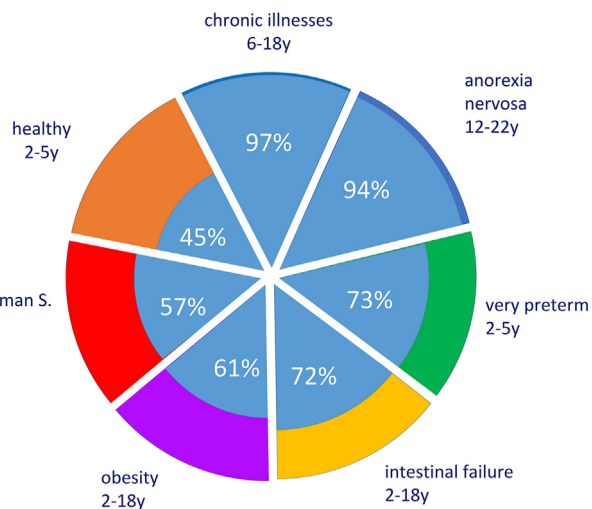
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4.2. Software

All but one research physician reported concerns about the reliability and validity of the BOD POD, due to clinically questionable results. This might be due to algorithms and assumptions in the default settings of the provided software. The software algorithm that converts measured body volume and weight (e.g. body density) into fat mass percentage is based on multiple assumptions regarding density of fat mass (Dfm), density of fat-free mass (Dffm), prediction of surface area artifact and prediction of lung volume. The standard algorithm in the BOD POD software follows the assumption that the Dfm remains constant during life at 0.9007 kg/L(18, 22), which may not hold true for all pediatric patients. The default estimates for Dffm in children (according to 'Lohman et al.') in the BOD POD software were based on small studies from 1982 to 1989, in which findings of healthy older children and adults were extrapolated to children aged <8 years per 2-year intervals [18,22]. Recently, our research group provided a revised Dffm model to be used with BOD POD in healthy children aged 3−5 years based on 0.5-year intervals [7]. Earlier, Wells et al. developed Dffm estimates for healthy children 5 years or older [23], which have been reported to be superior to the default estimates in the BOD POD software for healthy children aged 5 years [24]. So far, these improved estimates have not yet been included in the BOD POD software by the manufacturer. Moreover, Dffm can vary in children with different nutritional status (i.e. hydration status), physical activity levels, ethnicity, and disease status [18,25]. As these variations are not included in current density models [18,19], inaccurate assumptions about Dffm lead to erroneous FM% results in specific pediatric patients.

Another potential explanation for the concerns about the BOD POD, is the software's assumption on thoracic gas volume (TGV), which is the sum of functional residual capacity and half of tidal volume. This can be measured in the BOD POD system using specialized equipment if the subject is extremely instructable and cooperative, which is seldom the case in pediatric patients. We, therefore, used the software's predicted TGV (based on the child's sex, age and height), using (extrapolated) data derived from 1 study in children aged 6−17 years [26]. However, some pediatric patients (i.e. preterm-born children with or without bronchopulmonary dysplasia (BPD)) have impaired lung function in mid-childhood [27], leading to overestimation of the TGV. This may potentially lead to an underestimation of FM% by BOD POD in such patients [28].

Lastly, the BOD POD's software makes assumptions about the air in the area next to the skin, which influences the device's volume measurement. This is referred to as: Surface Area Artifact (SAA). The ADP volume measurements are, corrected for a predicted SAA. This prediction is based on a sample of healthy subjects and is calculated using the child's height and weight, which are aberrant in some (chronic) pediatric illnesses [29]. This potentially leads to an incorrect prediction of SAA, and subsequently to an erroneous body volume measurement and FM% result [4].

4.3. Strengths and limitations of the study

To our knowledge, we are the first to combine user experience and data on the practical performance and subject compliance evaluation of the widely used BOD POD, which we consider a strength of our study. Furthermore, our results are based on a collaboration of 7 cohort studies conducting BOD POD measurements in healthy children and in children with various (chronic) illnesses. This resulted in a uniquely large number of BOD POD

measurements in a heterogeneous patient population aged 2−22 years. We also acknowledge limitations. Evaluation of user experiences are always subjective. We tried to objectify the results by using the validated UEQ, standardizing questioning of the involved physicians, nurses and dieticians, and extracting measurement data from the BOD POD device. All studies were conducted in Erasmus MC Sophia Children's hospital using one BOD POD device, which may limit generalizability to other centers. To validate our results, we encourage future multicenter studies to validate our user experiences and data observations in other pediatric patient groups. Furthermore, we found that the majority of research physicians reported concerns about clinically questionable FM% results. In literature, validation of BOD POD results has only been performed in healthy participants [5]. Ideally, BOD POD should also be validated in pediatric patients with various diseases or aberrant body weight. That requires comparison of BOD POD values to a reference method for body composition determination, which was not similarly available in all seven cohorts. Another limitation is that the respondents were asked to reflect on their past experience with the BOD POD retrospectively. Ideally, users have to give their opinion during or directly after using the BOD POD, to limit recall bias. Lastly, no data were available to study a learning effect over time.

4.4. Suggestions for improvement and directions for further research

Based on our findings, we recommend further validation of BOD POD use in different (pediatric) patient groups in clinical practice. Furthermore, we hypothesize that certain modifications may improve BOD POD measurements in children. First, adaptations to the pediatric seat and attached scale may improve usability and comfort in children with obesity, underweight or disabilities. A second, more technical, suggestion is to study whether systematically decreasing the volume ratio between chamber and subject could improve measurements in small and lean children. By placing a fixed volume in the chamber when using the 20 L calibration in the pediatric mode, may increase precision. Lastly, based on recent studies in young healthy and chronically ill children [7,23], we expect that adjustments of the BOD POD software, especially of the Dffm-estimates, will improve the validity of BOD POD use in children. Further research is needed to study these adaptations. Furthermore, a prospective study design is warranted to assess the most ideal and clinically feasible conditions (such as room temperature) contributing to the most valid measurements. For children under six, those with low or high body weight, and children with physical and intellectual disabilities, alternative methods may be more appropriate and yield more reliable results. Alternatives could include methods such as DXA and Bioelectrical Impedance Analysis (BIA).

5. Conclusion

We conclude that using ADP by BOD POD in children is non-invasive and user-friendly. However, in specific pediatric populations, BOD POD has some limitations and high (technical) failure-rates, especially in young children with aberrant body composition. We recommend caution when interpreting body composition results of pediatric patients as assessed with BOD POD using the current default settings. Future studies are needed to validate the use of BOD POD in specific pediatric populations, and to explore potential improvements to both hardware and software, especially in children with aberrant body composition.

Author contributions

KJ, AHK, AB, IvB and MV were in charge of designing the study. IvB & DD & AHK, AB & VB & MV & KJ, SB & EvdA, LV & BK, KB & GD, LS, DH & PA & KBdH were in charge of the separate cohorts. AB and IvB performed questionnaires and interviews. AB and IvB were in charge of data collection. Statistical analysis was performed by AB and IvB. Drafting the manuscript was primarily done by AB and IvB under supervision of MV, AHK and KJ. All authors were involved in writing the manuscript and had final approval of the submitted version.

Conflict of interest

Acknowledgements

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2023.07.003.

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