Bioelectric impedance vector analysis (BIVA) in hospitalised children; predictors and associations with clinical outcomes

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Running title: BIVA in paediatric patients

Abstract

Background: Clinical use of bioelectric impedance is limited by variability in hydration. Analysis of raw bioelectric impedance vectors (BIVA), resistance (R), reactance (Xc) and phase angle (PA) may be an alternative for monitoring disease progression/treatment. Clinical experience of BIVA in children is limited. We investigated predictors of BIVA and their ability to predict clinical outcomes in children with complex diagnoses.

Methods: R, Xc and PA were measured (BODYSTAT Quadscan 4000) on admission in 108 patients (4.6-16.8 years, mean 10.0). R and Xc were indexed by height (H) and BIVA-SDS for age and sex calculated using data from healthy children. Potential predictors and clinical outcomes (greater-than-expected length-of-stay (LOS), complications) were recorded.

Results: Mean R/H-SDS was significantly higher (0.99 (SD 1.32)) and PA-SDS lower (-1.22 (1.68))) than expected, with a wide range for all parameters. In multivariate models, the Strongkids risk category predicted R/H-SDS (adjusted mean for low, medium and high risk = 0.49, 1.28, 2.17, p=0.009) and PA-SDS (adjusted mean -0.52, -1.53, -2.36, p=0.01). BIVA-SDS were not significantly different in patients with or without adverse outcomes.

Conclusion: These complex patients had abnormal mean BIVA-SDS suggestive of reduced hydration and poor cellular health according to conventional interpretation. R/H-SDS was higher and PA-SDS lower in those classified as higher malnutrition risk by the StrongKids tool. Further investigation in specific patient groups, including those with acute fluid shifts and using disease-specific outcomes, may better define the clinical role of BIV.

Abbreviations:

BIA - Bioelectric impedance analysis
BIVA - Vector BIA
CKD – Chronic kidney disease
FM - Fat mass
FFM - Fat-free mass
EN – Enteral nutrition (commercially formulated liquid feed)
LM- Lean mass
LOS - Length of stay
PA - Phase angle
PN - Parenteral nutrition
R – Resistance
SDS - Standard deviation scores
Xc - Reactance
Z - Impedance

Background

Body composition measurements can be informative in paediatric patients as fat and lean mass may differentially affect disease progression and response to treatment; they are also important when calculating requirements for dietary/fluid intake and doses for different types of treatment (1). Various methods are available for assessment of body composition, ranging from simple bedside techniques to multicomponent models suitable only in a research setting (1, 2). Bioelectrical impedance analysis (BIA) is increasingly used as it is non-invasive, safe, inexpensive and portable. It measures the resistance of the body to a small electric current, but prediction of body water or fat free mass relies on the assumption that conductivity is proportional to body water and that the hydration of lean tissue can be reliably predicted. These assumptions are not always valid even in healthy children, and are a particular problem in clinical situations where hydration is altered. BIA prediction equations are also population-specific and have poor accuracy in individuals (2).

Biolectrical impedance vector analysis (BIVA) as developed by Piccoli is a graphical method that relies on qualitative rather than quantitative analysis of BIA components, avoiding the need for potentially erroneous assumptions (3). Impedance (Z) is decomposed into its raw values of resistance (R) and reactance (Xc) which are plotted on 'R/H-Xc/H' graphs, where data from a population are expected to form an ellipse with one diagonal axis representing variability in hydration, and the orthogonal axis representing variability in body cell mass, a proxy for lean mass (4). Individual data points on this graph can be characterised by a vector, whose angle relative to the x-axis is termed 'phase angle'. Phase angle (PA, equal to tan−1(Xc/R)) has been

proposed as a simultaneous marker of cell mass and cellular health, providing an index of clinical status, and several studies broadly support this hypothesis (5-8). In one large adult study, fat-free mass (FFM) was the strongest predictor of phase angle (9). Furthermore, major longitudinal changes in hydration correlate with changes in the ratio between R/H and Xc/H, for example in adults undergoing hemodialysis (10). The use of BIVA in paediatric patient groups has been less studied.

Vector distribution patterns have been shown to be influenced by sex, race or ethnicity, BMI and age in both adults and children (11, 12). In particular, we have shown a clear impact of age in healthy children, with vectors progressively shortening towards the adult position with increasing age in both males and females (13), suggesting the need to consider age when interpreting BIVA data.

The aim of this study was to evaluate the use of BIVA in children admitted to a tertiary children's hospital, using BIVA parameters normalised for age and sex (13). Specifically, we (i) describe the impact of disease on BIVA parameters; (ii) investigate predictors; and (iii) assess whether BIVA parameters on admission predict clinical outcomes. We also explore associations between BIVA parameters and body composition measurements by another method (dual-energy X-ray absorptiometry (DXA)) in order to compare with findings reported in healthy children (12) and to assist with the interpretation of BIVA vectors.

Methods

Study population

Children aged ≥5 years (reflecting the age range of available body composition reference data) were recruited from all wards of a tertiary/quaternary paediatric hospital in London, UK for the BodyBasics study. Inclusion criteria were deliberately broad in order to include an extensive range of diagnoses; all children newly admitted, with expected hospital stay ≥3days, able to have baseline measurements within 48 hours of admission and before major procedures or treatment were approached. No patient groups were excluded *a priori*, provided individual children met the inclusion criteria. Ethical approval was obtained from the NRES Committee London-Central. Parents or patients ≥16 years gave written informed consent and assent was obtained from children <16 years.

Data Collection

BIA was measured using BODYSTAT Quadscan 4000 at a frequency of 50 khz, as proposed by Piccoli (3). Measurements were recorded with the subject lying supine with no body parts touching one another. Surface electrodes were placed on the left wrist (next to the ulna head and behind the knuckle of the middle finger) and ankle (at the level of the medial and lateral malleoli just below the toes). Two consecutive measurements were taken, and mean R, Xc and PA values calculated. The technical error of measurement (TEM) values (calculated as the square root of the sum of squares of differences between measurements divided by twice the sample size) were: PA 0.024, R 1.0 Ω, Xc 0.28 Ω.

Body composition (fat mass (FM) and lean mass (LM)) was measured using DXA (Lunar Prodigy (GE Medical Systems, USA)). Patients wore light indoor clothing and

scans were performed with the patient lying supine. LM was calculated as the sum of lean tissue and bone mineral content.

Weight was measured to the nearest 0.01 kg using a standing, sitting or hoist electronic scale (Seca, Germany). Children were asked to remove their shoes and measured in light clothes where possible. Height was measured to the nearest 0.1 cm using a wall-mounted digital display stadiometer (Seca, Germany) or Harpenden wall-mounted stadiometer, or for infectious patients, a portable mechanical stadiometer which was taken into the patient's room. A measuring mat was used where possible if the child was unable to stand. Weight and height measurements were taken in duplicate and the mean value used. BMI was calculated in kg/m^2.

Predictor variables

Physical activity level, wheelchair use, high-dose steroid treatment in the past 6 months, the use of parenteral (PN) or enteral (EN) nutrition support at the time of admission, and the main reason for admission (classified as investigation, acute medical treatment and surgery) were considered as potential predictors of BIVA-SDS. These variables were selected rather than using disease categories given the complex nature of the patients, the majority of whom had multiple diagnoses. Parents were asked to rate their child's physical activity level compared to their peers as 'much less', 'less', 'same', 'more' or 'much more'. Dietary intake was assessed in terms of reliance on nutrition support (enteral or parenteral), categorised as none, partial or full. Wheelchair use was categorised as 'yes' (regular use) or 'no'. Steroid treatment in the past 6 months was designated as 'high' or 'low' dose based on the opinion of

the patient's clinical team and coded 'yes or 'no'. Three malnutrition screening tools (MSTs) were applied on admission by one of four investigators in the same order: 1) PYMS (14); 2) STAMP (15); 3) STRONGkids (16). These tools included questions related to the child's nutritional intake, current nutritional status, increased losses and/or requirements, and risk associated with the underlying disease. Scores were used to categorise patients into low-risk (LR), medium-risk (MR) or high-risk (HR) categories,

Clinical Outcomes

Data on length of stay (LOS) and complications were collected when the child was discharged from the hospital or after 3 months if still an inpatient. These outcomes were chosen because they could be obtained from all patients regardless of their clinical condition.

The absolute LOS in hospital was expected to be highly variable, so the actual stay was compared to the predicted LOS on admission based on the judgement of the clinical team and standard times for scheduled procedures. LOS was categorised as 'increased' versus 'expected'; an 'increased LOS' was defined as LOS longer than predicted and greater than the median of 9 days, to avoid classifying patients as having increased LOS when this was only 1-2 extra days and for administrative reasons unrelated to their clinical condition.

A patient was considered to have experienced 'complications' during their stay if they had any of the following: 1) transfer to the Intensive Care Unit or to their local

hospital rather than discharge home, 2) unplanned increased reliance on artificial nutrition (EN and/or PN), 3) periods of fever or infection treated with antibiotics.

Statistics

R and Xc were indexed by height to generate R/H (ohm/m), Xc/H (ohm/m) and converted to SDS for age and sex using data from a cohort of 293 healthy children (12). SDS for anthropometric variables and BC were calculated using UK90 reference data (17) and in-house reference data (18), respectively.

Statistical analysis was performed using SPSS Statistics 21.0 software (SPSS Inc. USA). One sample t-tests were used to compare the patient SDS with the reference population mean (i.e. a score of 0). For predictor and outcome variables, BIVA-SDS were compared between categories using independent sample T tests, ANOVA or non-parametric equivalent. Relationships between BIVA-SDS and body composition were examined using Pearson's correlation. Linear or logistic regression was used to examine predictors of BIVA parameters and/or clinical outcomes.

Results

Study Population

156 patients were recruited for the BodyBasics study. However, to minimise the contribution of measurement error, and given the need to standardise R and Xc by height, children in whom the height, BIA or weight measurement was considered to be suboptimal or compromised, or where the BIVA-SDS was implausible (<-6), were excluded from the current analysis. This left 70 subjects for analyses involving R/H-

SDS or XC/H-SDS. For analyses involving PA-SDS, which is independent of height, subjects were excluded only if the measurement of BIA was considered to be sub-optimal or the BIVA-SDS implausible, leaving 108 subjects. Further details of subject participation and reasons for exclusion are provided in Figure 1. Descriptive data on the main clinical specialty caring for each patient and the main reason for the current admission are shown in Figure 2. Within most specialty categories, patients were very heterogeneous and most had multiple diagnoses, hence this variable was not used in further analyses. However, the main reason for the current admission classified as 'investigation', 'acute medical treatment' or 'surgery' was considered as a potential predictor of BIVA parameters and clinical outcomes.

BIVA-SDS distribution

The mean XC/H-SDS of the patients was not significantly different from zero. However, mean R/H-SDS was significantly higher and mean PA-SDS significantly lower than the population mean. There was a wide range of values for all BIVA-SDS (Table 1). Similarly, there was a wide range of weight, height and body composition SDS; mean weight, BMI and FM were not significantly different from zero, but mean height and LM-SDS were significantly lower than expected.

Predictors of BIVA-SDS

Age was not significantly correlated with R/H-SDS (r=-0.11), XC/H-SDS (r=0.14) or PA-SDS (r=0.14) on admission. PA-SDS was significantly lower and R/H-SDS significantly higher in patients classified as high risk by the Strongkids MST. A similar pattern was seen for the STAMP MST, although the trend for PA-SDS was of borderline

significance (p=0.06). R/H-SDS was also higher in children admitted for acute medical treatment or surgery rather than for investigation (p=0.013). There was a trend for higher R/H-SDS and lower PA-SDS in patients receiving high dose steroids or EN/PN. In general linear models including age, reason for admission, Strongkids risk, high dose steroids and EN/PN, the only significant predictor of R/H-SDS and PA-SDS was the Strongkids risk category (adjusted mean R/H-SDS for low, medium and high risk = 0.49, 1.28, 2.17, p=0.009 (low versus high p=0.003, medium versus high p=0.02); adjusted mean PA-SDS for low, medium and high risk = -0.52, -1.53, -2.36, p=0.01 (low versus high p=0.003, medium versus high p=0.09)).

Clinical Outcomes

BIVA-SDS on admission were not significantly different in patients who did or did not develop the clinical outcomes of 'increased LOS' or 'complications' (Table 2), although there was a trend towards higher R/H-SDS in those with versus those without complications (mean difference 0.49, 95% CI -0.34 to 1.33) and in those with versus without an increased LOS (mean difference 0.42, 95% CI = -0.26 to -1.11). In logistic regression models including age, reason for admission, Strongkids risk, high dose steroids and EN/PN and either R/H-SDS or PA-SDS, no significant predictors of the clinical outcomes were identified.

BIVA-SDS and body composition *(Figure 1a,b,c).*

R/H-SDS was significantly negatively correlated with BMI-SDS (r=-0.54, p<0.001), LM-SDS (r=-0.86, p<0.001) and FM-SDS (r=-0.54, p<0.001).

XC/H-SDS was significantly negatively correlated with BMI-SDS (r=-0.29, p=0.02) and FM-SDS (r=-0.46, p<0.001), with a weaker, non-significant negative correlation with LM-SDS (r=-0.24).

PA-SDS was significantly positively correlated with BMI-SDS (r=0.22, p=0.02) and LM-SDS (r=0.47, p<0.001). No significant correlation was observed with FM-SDS (r=0.11, p=0.3).

Discussion

This group of children with a range of complex, generally chronic illnesses had abnormal age- and sex-standardised BIVA measurements, with significantly higher R/H-SDS and lower PA-SDS compared to healthy reference data. Following the conventional interpretation of these measurements, this would suggest these children have lower than expected 'body fluids' and worse 'cellular health'. However there was a wide range of values for each of the BIVA-SDS scores, most likely reflecting the heterogeneity of the group. The same variability was also seen for body composition SDS but the patients had significantly low mean height and LM-SDS compared to healthy reference data, consistent with the interpretation of worse 'cellular health' from PA.

Despite the finding of abnormal R/H and PA values for age and gender, only the risk category allocated for the Strongkids and STAMP MST and the reason for admission were significant predictors of these variables; patients classified as high risk had significantly higher R/H-SDS and lower PA-SDS, whilst those admitted for acute

medical treatment or surgery also had higher R/H-SDS. There was also a trend towards higher R/H-SDS and lower PA-SDS in patients receiving high dose steroids or PN/EN, consistent with a greater severity of illness. However, in multivariable models the only significant predictor of R/H-SDS and PA-SDS was the Strongkids risk category.

A previous study reported significantly higher SD scores for both R/H and Xc/H in children and adolescents with cystic fibrosis compared to healthy subjects (19) using BIVA reference data from healthy Italian children (20), although PA did not differ between the groups. Higher R/H was interpreted as indicating dehydration, whilst the higher Xc/H was suggested to reflect changes in the sodium content in the sweat of the patients, although values were not adjusted for age. Girma et al (21) investigated anthropometric and biochemical correlates of BIVA parameters in Ethiopian children with and without severe acute malnutrition (SAM). All three parameters were lower in children with SAM, and also significantly lower in oedematous than non-oedematous SAM patients. Whilst R/H and PA were strongly correlated with anthropometric measures, Xc showed stronger correlations with biochemical parameters such as albumin and chloride. Thus the authors suggested that Xc may reflect physiological rather than physical parameters.

We found no significant difference in BIVA-SDS on admission in patients who did or did not develop complications or those whose LOS was or was not increased. However, there was a trend towards higher R/H-SDS, suggesting lower body fluids according to the conventional interpretation of this vector, in children who developed complications or who had an increased LOS, although no child was reported to be

295 clinically dehydrated at the time. The lack of significant associations between BIVA
296 and outcomes could reflect the necessary use of generic outcomes combined with
297 the relatively small sample size, and further exploration should include more defined
298 patient groups in order to allow more informative predictors and outcomes to be
299 used. For example, higher SD scores for both R/H and Xc/H were significant predictors
300 of impaired lung function in children with cystic fibrosis, after adjusting for age and
301 sex (11).
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303 Although we did not *a priori* exclude any patient groups providing they met the
304 inclusion criteria, our final study population did not include children with chronic
305 kidney disease (CKD) receiving dialysis or those receiving intensive care, thus
306 excluding those most likely to have major acute fluid shifts. It is possible that BIVA is
307 more informative in acutely ill patients than in those with chronic disease, as
308 suggested by previous publications in children. Girma et al. (22) reported lower R, Xc
309 and PA in Ethiopian children with SAM compared to healthy children, as well as
310 correlations between baseline R and patient outcome. Longitudinal changes in these
311 patients were also broadly consistent with Piccoli's model. Bozzetto et al. (23)
312 evaluated relative hydration status in 2-14 year old patients (46 CKD without oedema,
313 21 oedematous nephrotic children with normal renal function, 15 in remission from
314 nephrotic syndrome). A progressive increase of mean vector position was found in
315 patients with CKD stage IV compared to stages II-III and patients in remission.
316 Additionally, progressive vector lengthening was observed in children with severe
317 renal disease, considered to indicate relative dehydration. Azevedo et al (24)
318 reported an association between low Xc/H and R/H in children admitted to a

paediatric intensive care unit and multiple organ dysfunction. Both R/H and Xc/H increased significantly between admission and discharge in survivors, while in non-survivors there was a trend for decreased values between admission and the last measurement obtained. Finally, the study by Hauschild et al (11) reported significantly longer vectors, interpreted as a combination of dehydration and reduced cell mass, in children with cystic fibrosis who had reduced lung function, compared to healthy children or those with CF and normal lung function. However, BIVA parameters were not adjusted for age or pubertal status.

Our primary aim was to determine whether BIVA parameters were associated with clinical predictors and outcomes. However, we also examined associations between BIVA-SDS and body composition, and found similar patterns to those previously reported in healthy children (14). Thus PA was significantly positively associated with lean mass and BMI, suggesting patients with higher LM and BMI have better 'cellular health', consistent with findings from a large study in healthy adults which reported that the strongest predictors of PA were age, height and FFM (9). The correlation between LM and PA was stronger in our cohort than reported in healthy children, perhaps due to the greater range of both LM and PA in this group. R/H was negatively correlated with LM, FM and BMI, with the strongest correlation for LM. According to conventional interpretation this suggests that greater tissue masses, particularly LM, are associated with higher 'body fluids', although it is not clear whether this interpretation refers to intra- or extracellular fluid, or indeed a combination. Xc/H was also significantly negatively correlated with FM and BMI, with a stronger correlation for FM than for BMI. Thus those with higher measured tissue mass, especially FM,

have a lower value for a marker commonly interpreted as indicating 'body cell mass', which is clearly difficult to explain. Similar but stronger correlations were reported in our analyses in healthy children (13), suggesting that the conventional interpretation of R and Xc in younger age-groups may be more complicated than originally thought. It could be argued for example that Xc, which relates to the opposition to current flow through membranes, might also be an indicator of 'cellular health'. It is also possible that the interpretation of BIVA parameters should depend on underlying clinical characteristics, in particular whether there are disturbances of hydration.

An alternative explanation for the observed associations between BIVA parameters and body composition is that they reflect residual effects of body shape that are not removed by indexing the vector measurements for height. Specific BIVA has been proposed as a potential solution to this problem, since R and Xc are indexed by a correction factor derived from arm, calf and waist circumferences divided by height. To date, this method has been used in adults and the elderly (25, 26), and studies are needed in healthy children, particularly to establish whether the same correction factor is appropriate. We were unable to use specific BIVA in our population as we did not have the necessary circumference measurements; indeed, waist circumference measurements may be difficult to obtain in children who may have organomegaly, ascites or recent surgery. Another potential method for further adjusting vectors would be to consider relative body proportions, for example limb length in relation to height. Theoretically, measurements of leg length could be obtained from DXA scans. However our previous attempts to do this in paediatric patients have been hampered

by difficulties in standardising measurements, especially in those in whom optimal positioning is not possible because of their underlying condition.

BIVA was originally proposed by Piccoli as a qualitative method using raw BIA data to avoid the need for assumptions in converting measurements to body composition. However, the strong dependence of BIVA parameters on age makes the use of this simple graphical approach problematic in children and we therefore converted measurements to SDS for age and sex. Whilst this differs subtly from Piccoli's method, it retains the important advantage of avoiding the use of assumptions or prediction equations to convert BIVA into body composition, and in that respect still has advantages over conventional BIA.

The strengths of this study include the use of SDS account for the effects of age and sex on vector components, allowing the investigation of the impact of other clinical factors. Furthermore we studied a fairly large group of children with complex clinical conditions. We avoided a significant impact of measurement error by excluding children in whom the measurement of BIA was considered to be compromised in any way and, for Xc/H and R/H-SDS, also when the height or weight measurement was compromised. However, the heterogeneity of our population also represents a weakness, because it precluded the use of specific indicators of clinical condition or outcome. We also did not assess pubertal status, which has been shown to influence BIVA parameters (27), although we adjusted for age and sex which will to some extent address effects of puberty on body size.

In conclusion, this group of children with complex clinical conditions had abnormal mean BIVA-SDS suggestive of reduced 'body fluids' and poorer 'cell health' according to conventional interpretation. These measures were related to MST risk according to the StrongKids and STAMP tools, and to the reason for admission, but were not apparently influenced by other factors considered as clinical predictors and were not significantly related to clinical outcomes; possibly reflecting the necessary use of generic predictors and outcomes in this heterogeneous population. Children with adverse outcomes showed a trend towards higher R/H-SDS on admission, suggesting lower 'body fluids'. Further investigation in specific patient groups, including those with acute fluid shifts and using disease-specific outcomes, may help to better define the clinical role of BIVA.

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Conflict of interest statement

Professor Wells has received two BIA machines gratis from Bodystat, used in previous research. Bodystat had no role or influence over the research reported here. The other authors declare no conflicts of interest.

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Figure legend

Figure 1. Subject flow through the study

Figure 2. Distribution of subjects by main clinical specialty. (a) n=70 subjects included for analysis of R/H-SDS and Xc-SDS; (b) n=108 subjects included for analysis of PA-SDS

Figure 3. Scatterplots of a) BMI SDS, b) lean mass SDS and c) fat mass SDS against BIVSDS

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Table 1. Descriptive data and baseline BIVA-SDS

n=70 unless stated		Number	%
Boys		38	54
Wheelchair use		9	13
Artificial[a] feeding	No	56	80
	Partial	9	13
	Full	4	6
Activity Level cf healthy children of the same age[b]			
	Much less	16	23
	Less	16	23
	Same	24	34
	More	7	10
	Much more	5	7
Receiving high dose steroids		10	14

	Mean (SD)	*95% CI[c]*	*Range*
Age (years)	9.97 (3.44)		4.6 to 16.8
Weight SDS	-0.29 (1.38)	-0.56 to 0.10	-5.02 to 2.75
Height SDS	-0.52 (1.31)	-0.83 to -0.21	-4.62 to 2.17
BMISDS	0.11 (1.20)	-0.17 to 0.40	-3.21 to 2.61
FMSDS (n=61)	0.054 (1.09)	-0.22 to 0.33	-3.02 to 2.07
LMSDS (n=61)	-0.92 (1.26)	-1.24 to -0.60	-4.79 to 1.61
XC/H-SDS	-0.05 (1.37)	-0.38 to 0.27	-3.98 to 2.84
R/H-SDS	0.99* (1.32)	0.68 to 1.31	-2.16 to 4.20
PASDS (n=108)	-1.22* (1.68)	-1.54 to -0.90	-5.95 to 5.05

Values are n(%) or mean (SD)

[a] parenteral or enteral nutrition; data missing for 1 subject

[b] Data missing for 2 subjects

[c] 95% confidence intervals for mean

*p<0.001; one-sample t-test vs 0.

Table 2. BIVA-SDS according to different categories of predictor and outcome variables. Values are mean (SD)

	PASDS	XCSDS	R/H-SDS
Predictors			
Main reason for admission			
Investigation (35, 26[a])	-0.97 (2.07)	-0.55 (1.53)	0.47 (0.95)
Medical treatment (35, 32)	-1.34 (1.45)	0.26 (1.26)	1.36 (1.44)
Surgery (39, 12)	-1.34 (1.49)	0.19 (1.02)	1.15 (1.40)**
Activity level			
Much less (n=25, 16)	-1.01 (1.45)	0.42 (1.00)	1.48 (1.39)
Less (n=25, 16)	-1.22 (2.0)	-0.31 (1.53)	0.78 (1.13)
Same (n=34, 24)	-1.39 (1.73)	-0.34 (1.50)	0.87 (1.13)
More (n=12, 7)	-1.18 (1.31)	0.14 (1.31)	0.61 (2.0)
Much (more n=7, 5)	-1.36 (2.25)	-0.09 (1.37)	1.16 (1.76)
Receiving EN/PN			
No (n=85, 56)	-1.19 (1.80)	-0.09 (1.40)	0.93 (1.38)
Partial (n=14, 9)	-1.29 (1.27)	0.01 (1.09)	1.21 (1.04)
Full (n=6, 4)	-1.49 (0.86)	-0.15 (1.09)	1.26 (1.2)
High dose steroids			
No (n= 95, 61)	-1.18 (1.75)	-0.10 (1.41)	0.92 (1.34)
Yes (n= 10, 8)	-1.62 (1.04)	0.07 (0.99)	1.49 (1.07)
Wheelchair use			
No (n=90, 60)	-1.25 (1.77)	-0.11 (1.37)	0.99 (1.34)
Yes (n= 13, 9)	-1.07 (1.12)	0.11 (1.42)	0.90 (1.15)
MSTs[b]			
PYMS			
Low (n=55, 39)	-1.06 (1.39)	-0.01 (1.20)	0.85 (1.22)
Medium (n=33, 15)	-1.19 (1.96)	-0.15 (1.0)	-0.06 (2.01)
High (n=20, 16)	-1.71 (1.90)	-0.06 (2.01)	1.23 (1.67)
STAMP			
Low (n=22, 11)	-0.57 (1.91)	-0.71 (1.52)	0.13 (1.04)
Medium (n=55, 38)	-1.21 (1.26)	0.09 (1.04)	0.97 (1.25)
High (n=31, 21)	-1.71 (1.90)*	0.03 (1.74)	1.49 (1.37)**
StrongKids			
Low (n=21, 11)	-0.28 (1.90)	-0.65 (1.66)	-0.06 (1.04)

Medium, (n=70, 43)	-1.34 (1.43)	-0.04 (0.84)	0.95 (1.08)
High (n=17, 16)	-1.88 (1.97)**	0.32 (2.11)	1.84 (1.56)***
Outcomes			
Complications			
No (n= 84, 57)	-1.21 (1.79)	-0.14 (1.45)	0.9 (1.30)
Yes (n= 21, 12)	-1.26 (1.25)	0.22 (0.78)	1.39 (1.40)
Increased LOS			
No (n=72, 47)	-1.13 (1.72)	-0.15 (1.38)	0.85 (1.18)
Yes (n= 33, 22)	-1.44 (1.65)	0.08 (1.35)	1.27 (1.58)

[a] First number = n for PASDS, second number = n for R/H-SDS and XC/H-SDS
[b]Malnutrition screening tools
*p=0.06, **p<0.05, ***p<0.005 ANOVA

Figure 1.

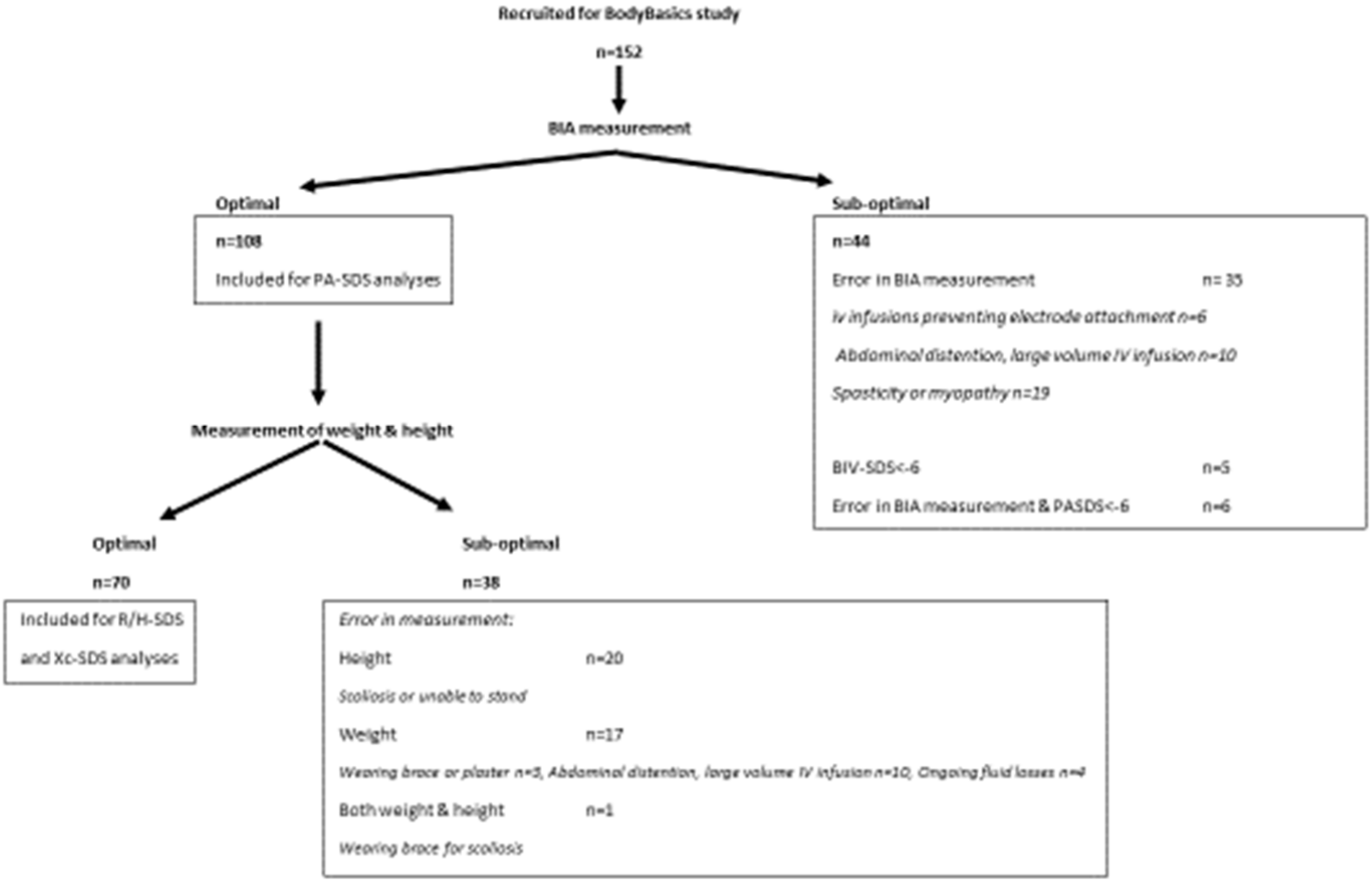
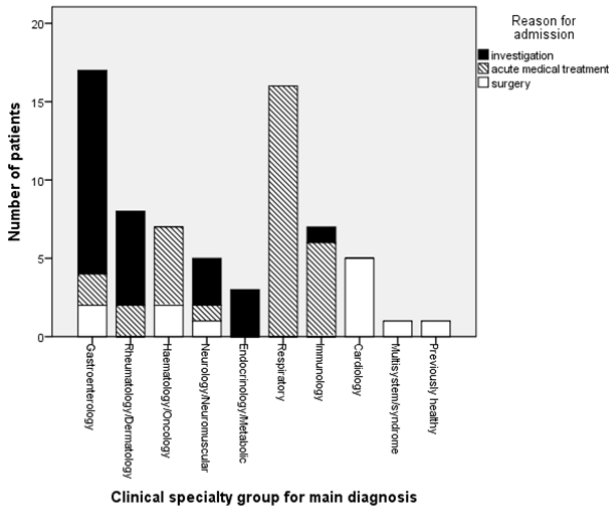

Recruited for BodyBasics study
n=152
BIA measurement
Optimal
n=108
Included for PA-SDS analyses
Sub-optimal
n=44
Error in BIA measurement n= 35
iv infusions preventing electrode attachment n=6
Abdominal distention, large volume IV infusion n=10
Spasticity or myopathy n=19
BIV-SDS<-6 n=5
Error in BIA measurement & PASDS<-6 n=6
Measurement of weight & height
Optimal
n=70
Included for R/H-SDS and Xc-SDS analyses
Sub-optimal
n=38
Error in measurement:
Height n=20
Scoliosis or unable to stand
Weight n=17
Wearing brace or plaster n=3, Abdominal distention, large volume IV infusion n=10, Ongoing fluid losses n=4
Both weight & height n=1
Wearing brace for scoliosis

Figure 2

a)


Reason for admission
investigation
acute medical treatment
surgery
Number of patients
20
15
10
5
0
Gastroenterology
Rheumatology/Dermatology
Haematology/Oncology
Neurology/Neuromuscular
Endocrinology/Metabolic
Respiratory
Immunology
Cardiology
Multisystem/Syndrome
Previously healthy
Clinical specialty group for main diagnosis

b)

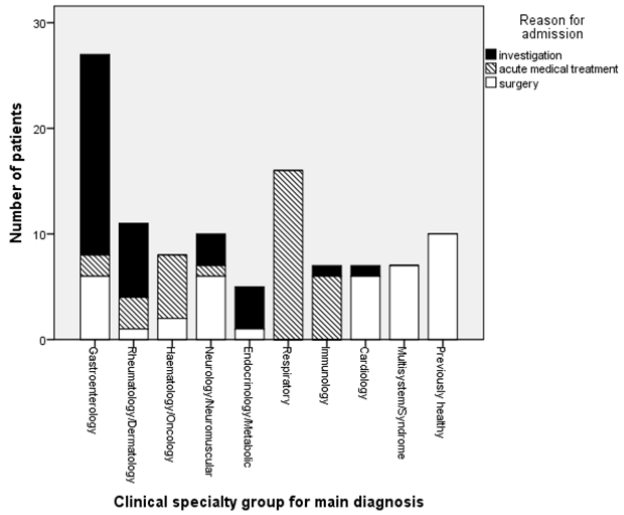
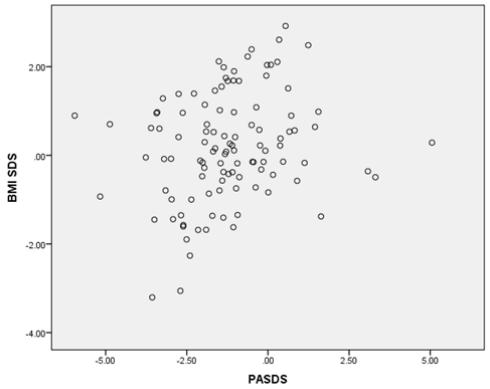
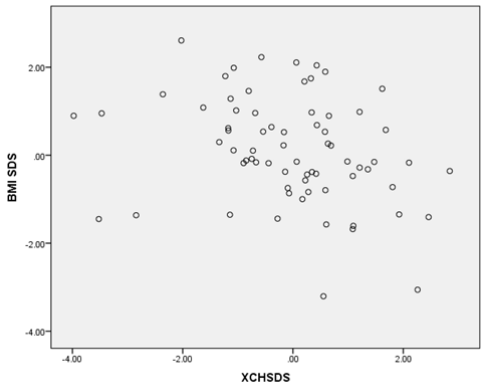

Reason for admission
investigation
acute medical treatment
surgery
Number of patients
30
20
10
0
Gastroenterology
Rheumatology/Dermatology
Haematology/Oncology
Neurology/Neuromuscular
Endocrinology/Metabolic
Respiratory
Immunology
Cardiology
Multisystem/Syndrome
Previously healthy
Clinical specialty group for main diagnosis

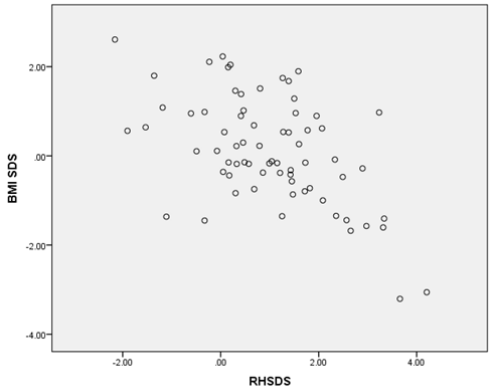
Figure 3a.



r=0.22, p=0.02

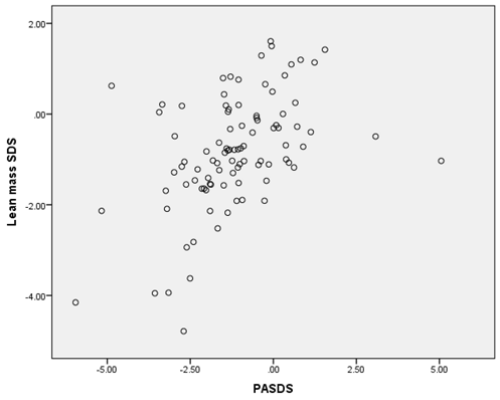


r=-0.29, p=0.02

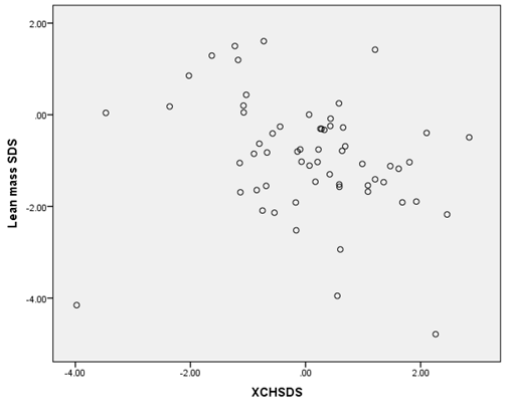


r=-0.54, p<0.001

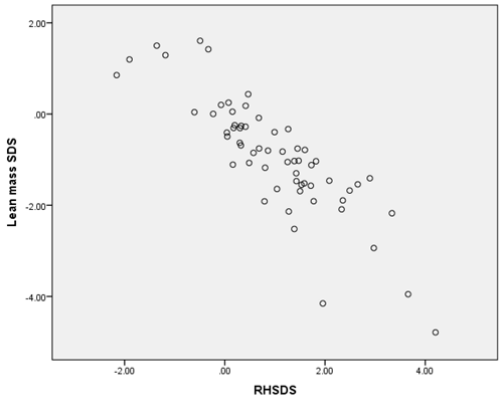
Figure 3b.



r=0.47, p<0.001

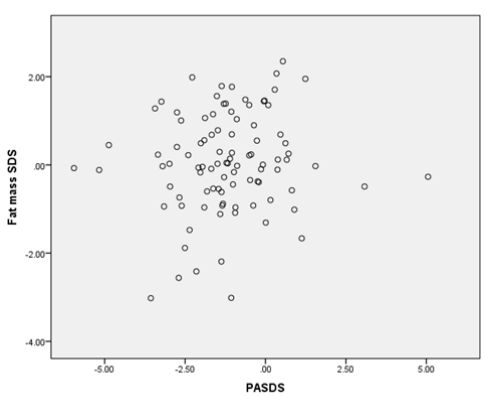


r=-0.24, p>0.05

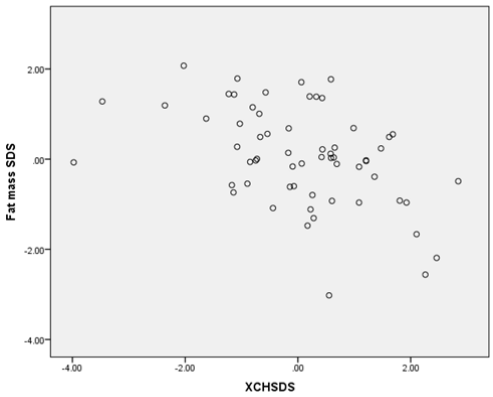


r=-0.86, p<0.001

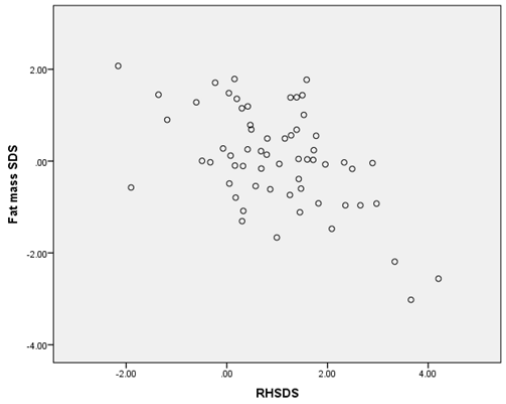
Figure 3c.



r=0.11, p>0.05



r=-0.46, p<0.001



r=-0.54, p<0.001