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Original article

Assessing fluid shifts in the pediatric surgical patient: is bioimpedance a promising tool

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Abstract

Background: **assessing the fluid status of pediatric surgical patients is still a difficult task**
Objectives: **assessing fluid shifts pre- and postoperatively in pediatric patients undergoing general anesthesia using bioimpedance spectrometry (BIS) and assessing BIS in practice as a tool for fluid research in the anesthetic setting.**
Design: **single center prospective pilot study**
Method: **we included pediatric surgical patients age 2-16 yrs, the Total Body Water (TBW) was measured using the Body Composition Monitor (BCM, Fresenius Kabi) pre- and postoperatively. anesthetic management was otherwise routine. All patients were fasted following the ESA Guidelines (2011) and were allowed to have oral intake postoperatively. IV Fluid maintenance rate was calculated by the "4/2/1"rule (Holiday and Segar), fluid boluses were given when necessary. A fluid balance was calculated for each patient.**
Results: **88 patients were screened, 28 included. 71% where male, median age (y) was 6 (IQR 3). 71% were in ambulatory setting. Median total fluid balance (ml/kg) was 27.3 (IQR 14), non-normally distributed. Mean TBW preop was 14.9 (95% CI:13.3;16.4) L and mean TBW postop was 14.4 (95% Ci: 12.8;15.9) L . the difference in TBW pre- and postop was non-significant (paired T test; 95% CI. p=0, 93; -0.33,1.36). There was no correlation between Total fluid balance and the TBW difference using Pearson correlation test (P= 0.32, 95% CI (-0.19, 0.52)).**
Discussion: **the BCM was not usable in the operating theatre due to electronic interference, limiting it's perioperative usage. It is however easy and comfortable to use in pediatric patients on the ward. Sample size was smaller than anticipated limiting the power of the study. Most surgeries were performed in ambulatory setting with limited blood loss, short IV running time and no fluid resuscitation resulting in no significant difference in TBW pre- and postoperatively.**
Conclusion: **the BCM is not usable in the OR environment, but further research in more fluid demanding surgeries are needed.**

Keywords: **Electric Impedance, Body Composition, Anesthesia, Pediatrics, perioperative care.**

Introduction

Perioperative fluid management of pediatric patients is a topic of great interest in the anesthetic community, as with all pediatric patients the anesthesiologist is forced to calculate every drug and fluid amount given in relation to the patient's body weight, and in contrast to adults the margins for fluid overloading or hypovolemia on the other side are very small.

Common practice during general anesthesia is to have a continuous intravenous (IV) fluid admission with the volume per time either based on, or calculated by the Holiday and Segar rule: (also

Disclaimer: This study, its protocols and informed consents were approved by the ethics comity of the university hospital Antwerp on 30.08.2021 with BUN number B3002021000164.
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known as the 4/2/1 rule: 4 ml/kg/h for the first 10 kg bodyweight, 2 ml/kg/h for the next 10 kg and 1 ml/kg/h for every kg body weight above the 20 kg total body weight[1].

In clinical practice following the Holiday and Segar rule means that the rate of the maintenance fluid can be higher than that of adult surgical patients in volume over time which would suggest that fluid overload could be an issue.

Challenging this longstanding and in clinical practice easy to use rule is not easy knowing that obtaining a correct fluid status in pediatric patients has been proving difficult. Many methods used in the adult surgical patients which do give quite accurate assessments of euvolemia do not translate to pediatric patients[2]. So how could we better obtain an assessment of the pediatric fluid status, and could we then have a better understanding of how and if, our perioperative fluid regimes cause either fluid overload or deficit?

In this study the researches used Bioimpedance spectrometry (BIS), it is a method relying on the body's natural resistance to electrical current to measure the fractions of water, fat and lean mass of the body. this method is neither new nor experimental, and has been used by both adult and pediatric nephrology departments in assessing fluid status in patients needing hemodialysis[3].

One of the BIS monitors widely used is the Body Composition Monitor (BCM) of Fresenius Kabi (Germany), in the context of anesthesia and perioperative management however, the use of bioimpedance hasn't been extensively researched. But promising results in measuring and correlating a positive perioperative fluid balance to an increase in TBW and overhydration has been seen in smaller trial[4,5]. This however might not be the same in the pediatric population.

The aim of the study is to evaluate if the BCM is a usable tool in the perioperative setting for pediatric patients, what practical barriers there might be and if we can correlate fluid balances of our patients to changes in the Total Body Water (TBW).

If so, maybe the BCM might be a tool we can use to further research different perioperative fluid regimes in the pediatric patient in a attempt to prevent fluid overload or deficit.

Methods

Ethics

This study, its protocols and informed consents were approved by the ethics comity of the university hospital Antwerp on 30.08.2021 with BUN number B3002021000164.

The study was designed in line with the declaration of Helsinki.

The Trial was registered in the ClinicalTrials.gov database with number NCT05220709 with protocol ID 2021-0576.

Design

This was a single center prospective observational pilot study in a tertiary teaching hospital. We included patients scheduled for general anesthesia in the university hospital aged 1 month to 16 years old needing either ambulatory day care surgery or overnight stay in the hospital.

We attempted to include 100 patients in a pragmatic approach but in this pilot study no power calculation was performed

Inclusion criteria were:

- Age 1 month to 16 year
- Scheduled for elective surgery or investigation under general anesthesia
- Day care or inpatient hospitalization
- Obtained informed consent from a parent or legal guardian and child if possible

Exclusion criteria were:

- Procedural sedations
- Inability to obtain a informed consent
- Critically ill patients for urgent surgery
- Patients who cannot lie still for performing correct measurements on the bio impedance monitor for example: syndromic children or mentally disabled.
- Patients with kidney diseases
- Patients weighing > 50 kg (who do not receive IV fluids calculated with the 4/2/1 rule due to local protocols)

Protocol:

BCM measurements were attempted in the preoperative holding rooms of the operating theater or on the ward.

The weight of the child (in kg) and size (in cm) were measured, blood pressure was measured non-invasively with an automated blood pressure monitor.

The BCM measurements were performed according the methods published[3,6]:

The patient was placed in a supine position and 4 electrodeswere attached: 2 on the dorsal side of the hand, 1 located proximal of the wrist and 1 distally, and 2 electrodes on the ipsilateral foot with one electrode proximal of the ankle joint and one distally. Age, sex, blood pressure, weight and length were inputted before the start of the measurement. The measurement takes on average one to two minutes to complete and the data is saved onto a chipcard which is afterwards read out

in the BCM data management program.
After the first BCM measurement the patient was brought to the operating theatre where anesthetic management was performed without changes to the center's routine protocols.

These protocols dictate the usage of a isotonic IV fluids with 1% of glucose (Kidyalite, Fresenius Kabi) as the mainstay IV fluid from the age of 1 month till 6 years, above that age a non-glucose containing isotonic crystalloid was used (Plasmalyte, Baxter). The rate of mainstay infusion was calculated by the Holiday and Segar rule without adaptations.

Induction could be intravenously (IV) or via inhalation anesthetics, depending on the general comfort of the patient to have an IV catheter placed pre-induction. There were no IV catheters placed on the ward preoperatively.

Once under anesthesia the attending anesthesiologist recorded the type and amount of all IV fluids given. This comprehends the mainstay IV fluid rate, IV boluses for hemodynamical necessity, blood products and all medication given.

Blood loss was recorded when measurable in aspiration devices, but no attempt to measure blood in compresses or surgical drapes was made. Urine output was recorded when possible via a bladder catheter.

Once in the recovery room the same data were obtained regarded fluids given and lost, but also the own peroral intake was registered.
When discharged to the ward a fluid balance was kept for all IV and oral intake minus the urine loss (by weighing saturated diapers, urine catheter output or potty).

The second BCM measurement was then taken after discontinuation of IV medication or infusions before discharge to home.

All patients were fasted based on the ESAIC guidelines[7]

- 6 hours for solid food
- 6 hours for milk formula fed baby's
- 4 h for breast feeding
- 2 to 1 h for clear fluids.

Data gathering

BCM Measurements were performed by trained research staff and in presence of the patients parents.
No sedation or other interventions were performed in case the child was not lying still enough to get an accurate measurement, this lead to exclusion of the patient from the study however.

The BCM controlled the quality of measurement, if necessary a repeat measurement would be performed.

Data handling

All data from included patients was saved in REDCAP, a software vault for data research. Patient data was blinded and BCM measurement results were allocated to a designated research laptop.

Statistical analysis

All statistical analyses were performed with R v4.0 or above (R foundation, Vienna, Austria). Normality was tested with the Shapiro-Wilk test. We report the mean with standard deviation for normally distributed variables and the median with interquartile range (IQR) for asymmetric distributions. We report the count (n) and relative frequencies (%) for categorical variables.
The total fluid balance of each patient was calculated as the difference between the intake of fluid between BCM measurements (both IV and peroral) and the fluids lost (urine, blood), divided by the weight of the patient:

$$total\ fluid\ balance\ (ml/kg) = \frac{fluid\ intake\ (ml) - fluid\ output\ (ml)}{body\ weight\ (kg)}$$

The difference between total body water pre- and postoperative was tested with the Student's paired t-test (if the difference was normally distributed and after testing with Bartlett homogeneity test) or the paired Wilcoxon signed-rank test (otherwise).
We use Pearson's test to assess the correlation between the difference in TBW (pre- versus postoperative) and the fluid balance.

The threshold for statistical significance is set at 0.05.

Results

Population

We screened patients from 1/4/2022 till 6/2/2023, 88 patients were screened from which 28 patients were included for analysis (Figure 1). Most patients were excluded for either not giving an informed consent, or having a mental or physical handicap which didn't allow for them to lie still to receive a correct measurement.

Lying still was particular difficult in children aged under 2 years old.

From the 28 patients included 71% were male and 29% were female.

The median age (yrs.) was 6 with an IQR of 3. The youngest patient was 3 yrs and the oldest 15 yrs.

The vast majority of our surgeries were in ambulatory day care setting (n=20) with short stay hospitalization being second (n=6) and a minority needing a long stay hospitalization (n=2).

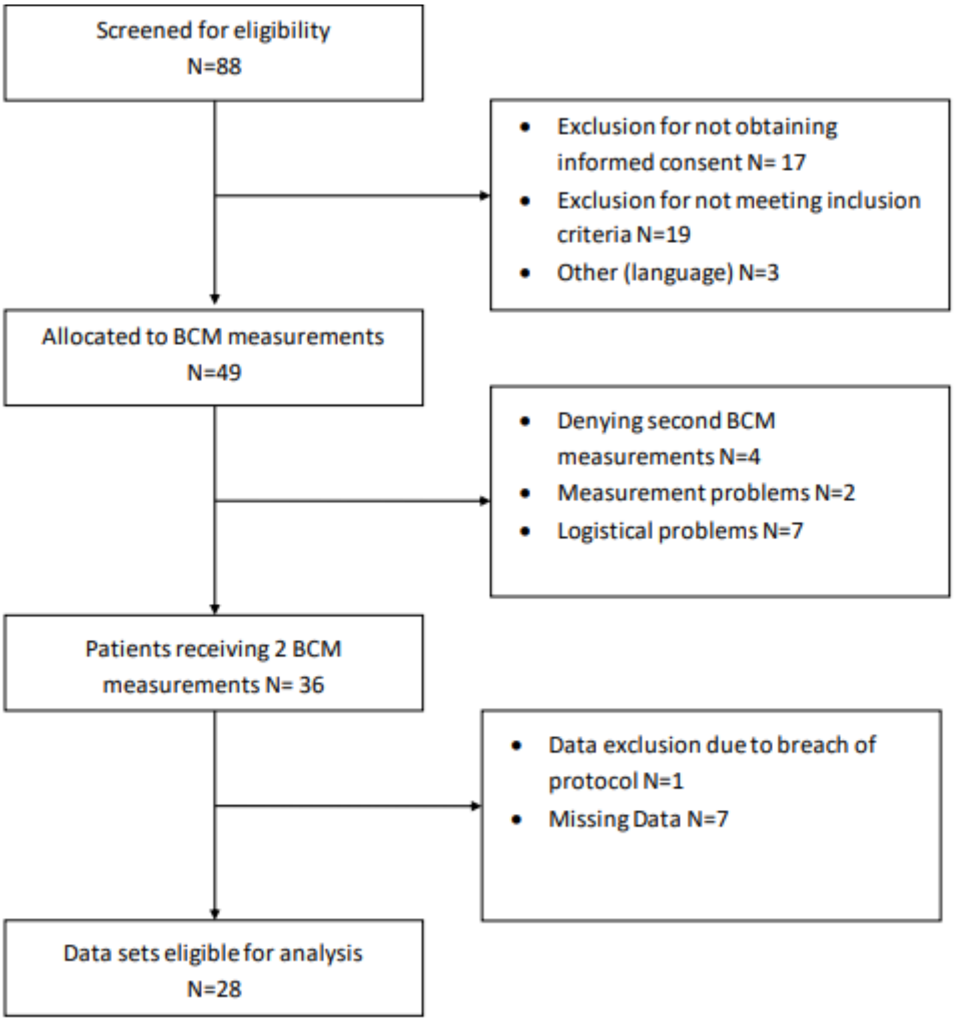

Fig. 1 — Patient selection.

Fasting times ranged from 1h30min till 22h40min with a median time of 9h45min.

Time between BCM measurements was median (h:min) (range) 7:35 (1:30;28:50). For further demographic data please see Figure 2.

BCM measurements in the confining of the OR were not possible as they took sometimes more than 5 minutes in test persons to obtain a result which was often then disregarded by the BCM as not accurate. When tried with pediatric patients this long measurements resulted in too much moving for any measurement to be accurate. The researchers then decided to shift the measurements to the ward which improved measuring times and accurateness.

Fluid Balance

Median total Fluid balance (ml/kg) was 27.3 with IQR of 14 (Figure 2).

The total Fluid Balance showed a non-normality using the Shapiro-Wilk test (p=0.0005).

Body Composition monitoring.

TBW preop and TBW postop are normally divided:

TBW preop: W= 0.95, p-value = 0.18
TBW postop: W = 0.95, p-value = 0.18
Mean (95% CI) TBW preop was 14.9 l (13.3;16.4)
Mean (95% CI) TBW postop was 14.4 l(12.8;15.9)
TBW 1 and TBW 2 were strongly correlated when using the Pearson's test (0.97; 95% CI (0.94;0.98)) (Figure 3).

The difference between TBW 1 and TBW 2 was non statistical significant when performing the paired T test (P= 0.93, 95 %CI (-0.33; 0.36))

This was done after performing the Bartlett homogeneity test (Bartlett's K-squared = 0.093539, df = 1, p-value = 0.7597)).

There was no correlation between Delta fluid/kg body weight and TBW difference when performing Pearson correlation test:

P= 0.32, 95% CI (-0.19, 0.52) with sample correlation of 19% (Figure 4).

Discussion

Using the BCM in the confining of the OR was quickly abandoned due to measurements taking too long or not being accurate enough, we hypothesis

Patient	Age (yrs)	Sex (m/f)	Surgery	Stay	Fasting time	Weight
1	7	Male	Cleft repair	Hospitalisation	22:40	24,30
2	5	Male	Tympanostomy tubes	Daycare	6:44	21,40
3	8	Female	Ureter stenting	Daycare	17:00	23,90
4	15	Female	tympanoplasty	Short stay	17:49	43,10
5	5	Female	adenotomy	Daycare	17:42	27,10
6	6	Male	cholesteatomy	Short stay	3:32	26,20
7	6	Male	circumcision	Day care	3:00	21,20
8	6	Male	Dental care	Day care	12:48	20,60
9	8	Male	laryngoscopy	Day care	4:35	28,60
10	6	Male	Tympanostomy tubes	Day care	9:17	17,60
11	4	Male	Dental care	Day care	13:59	17,10
12	5	Male	Tympanostomy tubes	Day care	12:00	20,90
13	9	Male	Dental care	Day care	14:00	28,70
14	8	Female	Cleft repair	Day care	5:36	30,10
15	11	Male	Dental care	Day care	10:30	34,20
16	8	Male	Laparascopic hernia repair	Day care	13:55	25,50
17	5	Male	rhinoscopy	Day care	13:00	23,30
18	4	Female	Dental care	Day care	2:230	17,00
19	4	Male	Tympanostomy tubes	Day care	15:00	20,50
20	7	Male	circumcision	Day care	9:35	25,70
21	3	Female	cholesteatomy	Short stay	4:35	18,90
22	11	Male	Cleft repair	Short stay	15:00	40,50
23	6	Male	cholesteatomy	Short stay	6:10	18,60
24	4	Male	cystoscopy	Day care	6:42	15,00
25	6	Male	orchidopexy	Short stay	3:12	20,40
26	5	Female	External ear repair	hospitalisation	1:31	19,60
27	4	Female	Laparascopic briden ressection	Day care	5:53	21,00
28	11	male	adenotomy	Day care	15:08	29,70
(demographic data of patients N=28, age in years; hospitalization= >1 night stay, short stay= 1 night stay, day care= ambulatory care; fasting time in hh:min, Weight in Kilograms).						

Fig. 2 — Demography.

that this is due to the electrical interference of medical and monitoring equipment readily present in the OR. Measurements taken on the ward in a far more electrical neutral environment away from monitors and other equipment went in general quite smooth. But as such the time between measurements pre and postoperatively increased.

The BCM was however in practice easy to use in even our youngest participating patients and no negative or harmful effects were reported.

We could not obtain a statistical significant difference in the total body water difference pre and postoperatively, nor a correlation between fluid balance and total body water difference. But this might be heavily influenced by the small sample size, the overall short duration of IV fluid's given, and that most cases were minor surgical interventions. As such is making definitive conclusion's about the BCM monitor as a tool for fluid changes in the perioperative setting difficult.

In our design we didn't wanted to interfere with the fluid protocols used in our standard of care and as such we have a combined fluid intake both intravenous and per oral postoperatively. When trying to evaluate the effect of the intravenous fluid regimes alone and it's impact on the total fluid balance and shifts perioperatively with the BCM, one would have to make an protocol which excludes pediatric patients postoperatively from any per oral intake until the postoperative BCM measurement can take place. This was in this pilot study with most patients in day care setting not deemed appropriate by the researchers.

Also, the fluid balance of pediatric patients in the perioperative setting is extremely difficult to

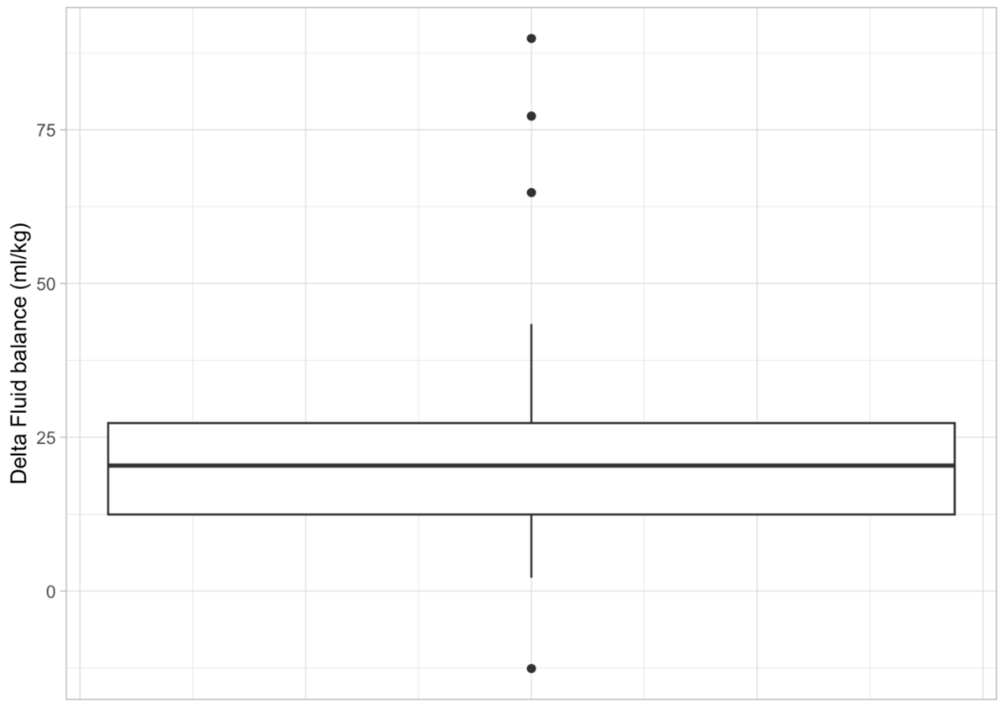

Fig. 3 — Distribution fluid Balance.
(fluid balance= all fluid in- all fluid lost/kg body weight, non normally distributed according to Shapiro-Wilk test).

get accurate. When an IV line is placed it can be left running before being placed in a electronic dispensing system, or a fluid bolus when not given by syringes or metric systems can lead to missing data.

The output of perspiration or blood loss was not registered due to its difficulty of being correctly measured, especially blood loss in surgical compresses or drapes[8]. We accepted these limitations in our design of the study.

The inclusion of patients in more complex surgical cases with more fluid shifts and longer IV running times could give different results in the pre and postoperative BCM measurements and might give statistical significant results, however this would require a far more complex fluid protocol

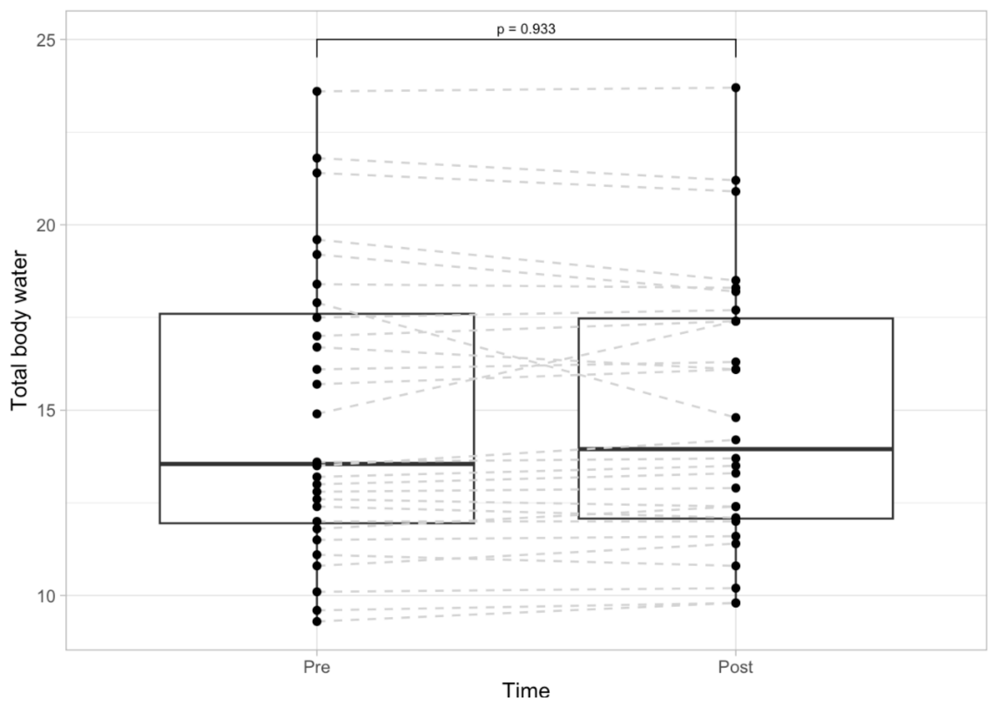

Fig. 4 — Delta TBW correlation (l).
(Delta TBW= TBW postop-TBW preop, both TBW are normally divided and strongly correlated using the pearson test (0.97; 95% CI (0.94;0.98)).

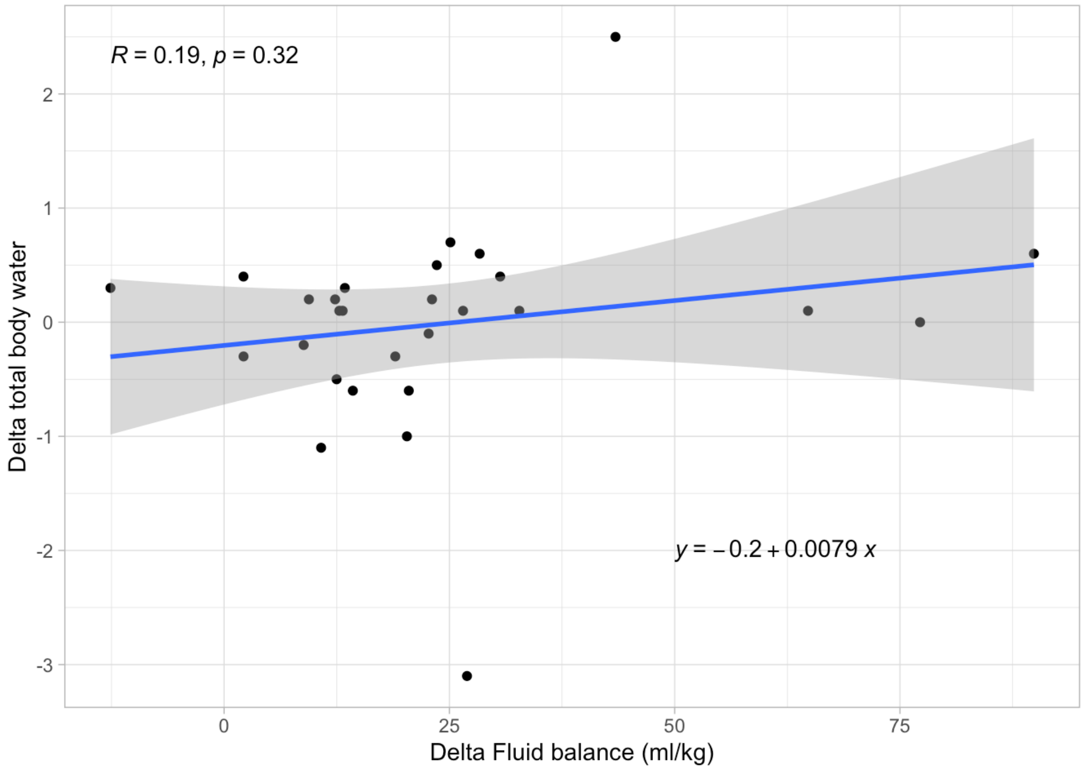

Fig. 5 — Pearson correlation test delta TBW (l)/Delta Fluid balance (ml/kg).
Correlation between Delta fluid balance and delta Total Body water using the Pearson correlation test, this showed no correlation P= 0.32, 95% CI (-0.19, 0.52).

and data gathering which was in this pilot study not feasible.

While reviewing the data we also observed the overall long fasting of our patients with median times more than 9 hours, we try to aim for water and apple juice intake until 1h before surgery in our center[9] The adverse effects of these prolonged fasting has already been well discussed and evidently require more attention and participation of both parents and clinicians.

When looking to future research we would advise in inclusion of patients requiring longer hospitalization and intravenous therapy with the possibility of more postoperative measurements being taken and more time between measurements.

Conclusion

The BCM is not usable in the OR environment due to electrical interference and showed in our study population no correlation between TBW difference and fluid balance. However, more research in fluid demanding surgeries should be done before making definitive statements about it's usability in further research.

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