research article

Comparative assessment of hydration status in intestinal failure patients receiving home parenteral nutrition using different bioimpedance analysis devices

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Background. Intestinal failure patients receiving home parenteral nutrition (HPN) are at high risk of dehydration and malnutrition. To optimize clinical care, accurate monitoring tools are required. This study aimed to compare the accuracy of two bioelectrical impedance analysis (BIA) devices, one that offers only BIA results and the other that offers BIA results of bioelectrical impedance vector analysis (BIVA) and bioelectrical impedance spectroscopy (BIS), in assessing hydration and nutritional status in HPN patients.

Patients and methods. In a cross-sectional study, 55 adult HPN patients (33 males, 22 females; mean age 61.5 ±13.1 years) underwent BIA measurements using both devices during routine visits. Parameters measured included total body water (TBW), intracellular and extracellular water, fat-free mass, fat mass, and phase angle. Serum urea and creatinine served as hydration markers. Paired t-tests, Mann-Whitney U tests, and Spearman correlations were used for analysis.

Results. The BIA/BIVA/BIS analysis indicated dehydration in 69.1% of patients compared to 29.1% by BIA ($p < 0.001$) and showed stronger correlations with serum urea. It also classified more patients as malnourished (24.4% vs. 16.4%, $p = 0.436$). Correlation between hydration status and phase angle was more pronounced when using phase angle determined with BIA/BIVA/BIS.

Conclusions. BIA/BIVA/BIS measurements in the study demonstrated superior sensitivity in detecting dehydration and assessing nutritional status in HPN patients in comparison to BIA, supporting its use for improved clinical monitoring and management in this group of patients.

Key words: intestinal failure; home parenteral nutrition; bioelectrical impedance analysis; bioelectrical impedance vector analysis; bioelectrical impedance spectroscopy; hydration status

Introduction

Intestinal failure is a complex clinical condition characterized by the reduction of gut function below the minimum necessary for the absorption of macronutrients, water, and electrolytes. In such cases, intravenous supplementation is required to maintain health, nutritional status, or growth.[1,2] Intestinal failure may arise from a variety of underlying pathophysiological mechanisms, includ-

ing short bowel syndrome, intestinal fistulas, mechanical obstruction, motility disorders, and mucosal disease. The degree of functional impairment depends not only on bowel length but also on the remaining bowel's capacity for adaptation and absorption.[3] In patients where the absorptive function of the digestive system is impaired, dehydration can be a major problem due to the reduced ability to absorb fluids.[4,5] Dehydration has a significant impact on an individual's well-being, quality of life, and clinical outcomes, making regular monitoring essential.[6] Beyond hydration status, nutritional status is also profoundly compromised in intestinal failure patients, with malnutrition contributing to increased morbidity and mortality.

Among patients with intestinal failure, those with short bowel syndrome and receiving long-term home parenteral nutrition (HPN) represent a particularly vulnerable subgroup.[7,8] These patients are at high risk for both dehydration and malnutrition, which significantly affect their quality of life and clinical outcomes. Dehydration, in particular, is a common yet often underrecognized complication. The clinical assessment of hydration status is challenging due to the lack of a definitive diagnostic standard and the limitations of traditional markers such as serum urea and creatinine. Consequently, regular monitoring using multiple parameters is essential in clinical practice.[9] Monitoring of nutritional status should extend beyond BMI to include body composition assessment, as parameters such as muscle mass and fat-free mass provide more accurate indicators of nutritional status and functional outcomes.[10]

Bioelectrical impedance analysis (BIA) is a non-invasive method widely used for evaluating body composition and estimating hydration status. The diagnostic usage of BIA has increased because the equipment is portable and safe, the procedure is simple, non-invasive, and results are obtained rapidly.[11,12] Although BIA is reliable in healthy individuals, its accuracy is reduced in patients with fluid imbalances, such as those with intestinal failure.[12,13] Standard prediction equations used by BIA devices are typically developed for healthy populations, potentially leading to significant errors when applied to clinical populations with abnormal fluid distributions. Despite its limitations, BIA remains an accessible and practical tool in everyday clinical care, particularly when used for longitudinal monitoring within the same individual.

Given the increasing use of HPN and the burden of fluid imbalance in patients with intestinal failure, improving hydration assessment is essential. The present study aimed to evaluate the accuracy and clinical utility of two different BIA devices – one that offers only BIA results and the more advanced that offers a combination of BIA, bioelectrical impedance vector analysis (BIVA) and bioelectrical impedance spectroscopy (BIS) in monitoring hydration and nutritional status in patients receiving HPN. The BIA utilizes multifrequency bioelectrical impedance analysis primarily focused on assessing body composition parameters such as total body water, fat mass, and fat-free mass using four different frequencies.[14] In contrast, the more advanced BIA/BIVA/BIS offers enhanced diagnostic precision by employing a broader spectrum of multifrequency impedance measurements (50 frequencies from 5 kHz to 1000 kHz), enabling segmental analysis and improved differentiation between intracellular and extracellular water compartments.[15] Therefore, we hypothesized that the BIA/BIVA/BIS, which incorporates vector analysis and additional parameters, would show better agreement with clinical and laboratory hydration markers and would more accurately detect malnutrition.

Patients and methods

Study design and ethical approval

This cross-sectional observational study was conducted at the Department for Clinical Nutrition of the Institute of Oncology Ljubljana. Ethical approval was obtained from the National Medical Ethics Committee of the Republic of Slovenia (No. 0120-310/2019/9, dated December 10, 2019). All procedures were carried out in accordance with the ethical standards of the institutional and national research committees.

Participants

The study included patients with chronic intestinal failure treated with HPN who attend regular follow-up visits at the Department for Clinical Nutrition of the Institute of Oncology Ljubljana and provided written informed consent for participation in the study.

Measurement protocol

Measurements were conducted during routine clinical visits. Each patient underwent assessment with two BIA devices – only BIA QuadScan 4000 and more advanced BIA/BIVA/BIS Multiscan 5000

TABLE 1. Descriptive statistics of measured body composition parameters using the bioelectrical impedance analysis (BIA) device (Quadscan 4000)

	Min	Max	M	SD	Asm.	SEasm	Kurt.	SEspl	S-W	p
Fat mass										
kg	7.30	42.70	19.22	7.05	0.85	0.32	1.34	0.63	0.96	0.04
%	11.30	49.80	28.24	8.40	0.32	0.32	−0.05	0.63	0.98	0.61
Fat free mass (FFM)										
kg	28.40	70.70	48.90	11.30	0.14	0.32	−0.98	0.63	0.97	0.12
%	50.20	88.7	71.78	8.41	−0.32	0.32	−0.05	0.63	0.98	0.60
Dry lean mass (kg)										
	2.00	22.20	10.52	4.83	0.26	0.32	−0.55	0.63	0.98	0.43
Fat free mass index (FFMI) (kg/m²)										
	9.80	21.50	16.65	2.85	0.02	0.32	−0.70	0.63	0.97	0.24
Phase angle (°)										
	2.00	6.10	4.48	0.95	−0.33	0.32	−0.09	0.63	0.97	0.19
Total body water (TBW)										
l	26.80	54.2	38.53	7.28	0.26	0.32	−1.00	0.63	0.96	0.07
%	39.50	71.50	57.16	6.92	−0.15	0.32	−0.52	0.63	0.98	0.61
Extracellular water (ECW)										
l	12.60	23.20	17.13	2.59	0.34	0.32	−0.75	0.63	0.97	0.14
%	19.40	31.30	25.50	2.70	0.22	0.32	−0.40	0.63	0.98	0.51
Intracellular water (ICW)										
l	12.80	28.20	20.56	4.52	0.06	0.32	−1.12	0.63	0.96	0.06
%	22.60	36.50	30.25	3.57	−0.14	0.32	−0.98	0.63	0.97	0.15
Prediction marker										
	0.78	0.92	0.84	0.03	0.37	0.32	−0.04	0.63	0.97	0.28

Asm = asymmetry coefficient; Kurt = kurtosis; SEasm = standard error of asymmetry coefficient; SEspl = standard error of kurtosis; S-W = Shapiro-Wilk value

(Bodystat Ltd, Isle of Man, UK) – during the same visit. Body mass was measured using a calibrated medical scale (Seca 7997021099, UK), and height was retrieved from clinical records (measured annually using a wall-mounted stadiometer, Seca 206).

Both BIA assessments were performed in the supine position after a 10-minute rest period. Electrodes were placed on clean, dry skin at standardized anatomical landmarks: dorsally on the wrist and hand, and frontally on the ankle and foot, all on the right side of the body. The signal and measuring cables were connected according to manufacturer specifications.

The devices measured several parameters, including fat mass, fat-free mass, dry lean mass, total body water (TBW), intracellular water (ICW), extracellular water (ECW), phase angle, fat-free mass index (FFMI), and overhydration index (available only on the Multiscan 5000). The parameters were determined by the device's internal algorithm. The phase angle was calculated from resistance and reactance using the manufacturer's algorithm.

Laboratory data

Venous blood samples were drawn on the same day as the BIA measurements and analysed at the Institute of Oncology's central laboratory. Serum urea and creatinine were recorded as biochemical markers of hydration status.

Malnutrition

The GLIM (Global Leadership Initiative on Malnutrition) criteria are a globally endorsed di-

TABLE 2. Descriptive statistics of measured body composition parameters using the device of bioelectrical impedance analysis (BIA) / bioelectrical impedance vector analysis (BIVA) / bioelectrical impedance spectroscopy (BIS) (Multiscan 5000)

	Min	*Max*	*M*	*SD*	*Asm.*	*SEasm*	*Kurt.*	*SEspl*	*S-W*	*p*
Fat mass										
kg	6.90	40.50	18.15	6.73	0.86	0.32	1.38	0.63	0.95	0.03
%	11.40	47.30	26.59	7.87	0.41	0.32	0.04	0.63	0.98	0.39
Fat free mass (FFM)										
kg	30.90	73.00	50.00	11.19	0.24	0.32	−0.88	0.63	0.97	0.18
%	52.70	88.60	73.41	7.87	−0.41	0.32	0.04	0.63	0.98	0.39
Dry lean mass										
kg	7.80	31.30	16.76	5.43	0.42	0.32	−0.31	0.63	0.97	0.18
Fat free mass index (FFMI)										
kg/m²	10.70	22.10	16.99	2.71	0.08	0.32	−0.64	0.63	0.98	0.36
Phase angle										
°	2.50	6.20	4.61	0.90	−0.32	0.33	−0.19	0.64	0.97	0.22
Total body water (TBW)										
l	21.70	46.50	33.16	6.47	0.22	0.32	−0.88	0.63	0.97	0.24
%	32.90	64.80	49.21	6.68	0.04	0.32	−0.35	0.63	0.99	0.98
Extracellular water (ECW)										
l	10.70	23.20	15.98	3.10	0.38	0.32	−0.80	0.63	0.96	0.08
%	17.20	46.90	24.06	4.09	3.26	0.32	17.59	0.63	0.74	0.00
Intracellular water (ICW)										
l	9.00	25.20	17.24	3.86	0.10	0.32	−0.81	0.63	0.98	0.34
%	15.20	36.80	25.64	4.66	0.13	0.32	−0.13	0.63	0.99	0.91
Overhydration index										
l	0.50	7.40	2.89	1.59	0.97	0.32	0.83	0.63	0.92	0.00
%	0.60	11.50	4.34	2.30	0.78	0.32	0.75	0.63	0.96	0.05
Prediction marker										
	0.79	0.92	0.84	0.03	0.53	0.32	0.08	0.63	0.96	0.08

Asm = asymmetry coefficient; Kurt = kurtosis; SEasm = standard error of asymmetry coefficient; SEspl = standard error of kurtosis; S-W = Shapiro-Wilk value

agnostic framework for malnutrition, combining phenotypic criteria (unintentional weight loss, low BMI, reduced muscle mass) with etiologic criteria (reduced food intake or assimilation, and disease burden/inflammation).[16] In our study malnutrition was diagnosed according to GLIM criteria based on FFMI thresholds (< 17 kg/m² for males, < 15 kg/m² for females).[16]

Statistical analysis

Descriptive statistics were calculated for all variables, including means, standard deviations, and distribution characteristics. Normality of data distribution was assessed using the Shapiro-Wilk test. For normally distributed variables, paired t-tests were used to compare the two BIA methods. For non-normally distributed data, non-parametric Mann-Whitney U tests were employed. Chi-square tests were used to evaluate categorical differences. Associations between BIA-derived parameters and biochemical markers were assessed using Spearman correlation coefficients. All analyses were conducted using IBM SPSS Statistics v23 and Microsoft Excel 2016.

Results

Participant characteristics

A total of 55 patients (33 males, 22 females) undergoing home parenteral nutrition (HPN) were included in the study. The mean age was 61.5 years (SD ± 13.1). Body weight ranged from 44.0 to 98.0 kg, with a mean of 68.1 kg (SD = 13.55). The distribution showed minimal skewness (0.18, SE = 0.32) and slightly negative kurtosis (−0.63, SE = 0.63).

Comparison of bioimpedance devices

Body composition was measured using both the BIA and the BIA/BIVA/BIS (Table 1, Table 2). The two devices showed similar values for fat mass, fat-free mass (FFM), and fat-free mass index (FFMI). However, the BIA/BIVA/BIS consistently provided higher estimates of dry lean mass and lower values for total body water (TBW), indicating greater sensitivity to hydration status.

Phase angle values measured by the BIA/BIVA/BIS (mean 4.61°) were slightly higher than those measured by the BIA (mean 4.48°), while extracellular water (ECW) and intracellular water (ICW) distributions differed more significantly between devices.

The BIA/BIVA/BIS also provided an additional parameter – overhydration (OHY) – with an average value of 4.34% body weight, not available on the BIA.

TABLE 3. The correlation between blood hydration markers and parameters measured by both devices

	Multiscan 5000		Quadscan 4000	
	Urea	*Creatinine*	*Urea*	*Creatinine*
Total body water (TBW)				
l	−0.552**	0.257	−0.471**	0.332*
%	−0.185	−0.331*	−0.054	−0.286*
Extracellular water (ECW)				
l	−0.453**	0.283*	−0.465**	0.297*
%	0.007	−0.297*	0.145	−0.419**
Intracellular water (ICW)				
l	−0.573**	0.207	−0.499**	0.395**
%	−0.244	−0.253	−0.251	−0.025

*p < 0,05; **p < 0,01

Laboratory markers of hydration

Serum urea and creatinine were used as laboratory markers of hydration status. The mean urea level was 7.54 mmol/L and creatinine was 85.2 μmol/L. Both markers showed non-normal distributions.

Correlation analysis revealed a statistically significant negative correlation between TBW (and ICW) measured by the BIA/BIVA/BIS and serum urea levels (Table 3). This relationship was strong-

TABLE 4. Results of Mann-Whitney U test in measured parameters according to the applied method

	Multiscan 5000		Quadscan 4000		*Mann-Whitney U*	*p*
	M	*SD*	*M*	*SD*		
Total body water (TBW)						
l	33.16	6.47	38.53	7.24	897.50	< 0.001
%	49.21	6.68	57.16	6.92	626.50	< 0.001
Extracellular water (ECW)						
l	15.98	3.10	17.13	2.59	1148.00	0.03
%	24.06	4.09	25.50	2.70	985.00	< 0.001
Intracellular water (ICW)						
l	17.24	3.86	20.56	4.52	899.00	< 0.001
%	25.64	4.66	30.25	3.57	672.00	< 0.001

When comparing TBW-based dehydration detection with laboratory markers, the BIA/BIVA/BIS showed higher concordance: 25% alignment with elevated urea and 24% with elevated creatinine, compared to 7% and 9%, respectively, for the BIA (Table 5, Table 6).

TABLE 5. Comparison of the number of dehydrated patients based on blood measurements of urea and total body water

			Total body water (TBW)		
			Dehydration	*Normal hydration*	*Total*
BIA	Urea	Dehydration	4	16	20
	Urea	Normal hydration	12	23	35
	Urea	Total	16	39	55
BIA/BIVA/BIS	Urea	Dehydration	14	6	20
	Urea	Normal hydration	24	11	35
	Urea	Total	38	17	55

BIA = bioelectrical impedance analysis; BIS = bioelectrical impedance spectroscopy; BIVA = bioelectrical impedance vector analysis

TABLE 6. Comparison of the number of dehydrated patients based on blood measurements of creatinine and total body water

			Total body water (TBW)		
			Dehydration	*Normal hydration*	*Total*
BIA	Creatinine	Dehydration	5	9	14
	Creatinine	Normal hydration	11	30	41
	Creatinine	Total	16	39	55
BIA/BIVA/BIS	Creatinine	Dehydration	13	1	14
	Creatinine	Normal hydration	25	16	41
	Creatinine	Total	38	17	55

BIA = bioelectrical impedance analysis; BIS = bioelectrical impedance spectroscopy; BIVA = bioelectrical impedance vector analysis

er than the correlation observed with the BIA data, suggesting better concordance with clinical markers of dehydration. For creatinine, the associations were weaker and less consistent across devices.

Identification of malnutrition

According to GLIM criteria BIA identified 16.4% of participants as malnourished, while the BIA/BIVA/BIS identified 24.4%. However, the difference was not statistically significant ($p = 0.436$).

Sensitivity in detecting dehydration

Based on relative TBW thresholds (< 55% in men, < 50% in women), the BIA/BIVA/BIS identified significantly more dehydrated patients (69.1%) compared to the BIA (29.1%) ($\chi^2 = 17.61$, $p < 0.001$) (Table 4). This finding suggests that the BIA/BIVA/BIS detects dehydration earlier or with greater sensitivity.

Correlation with phase angle

Using a median phase angle of 4.65° as the cut-off, 49% of participants were classified as dehydrated. The BIA/BIVA/BIS showed 38% concordance with phase angle-based classification, while the BIA showed only 13% agreement. Although not statistically significant, the BIA/BIVA/BIS showed better alignment with functional hydration markers such as phase angle.

Discussion

This study compared the performance of two BIA devices in assessing hydration and nutritional status among patients with intestinal failure on home parenteral nutrition. The results suggest that the newer and more advanced BIA/BIVA/BIS offers clinically meaningful advantages over the BIA,

particularly in detecting dehydration and aligning with biochemical and functional markers.

One of the most important findings was the BIA/BIVA/BIS's stronger correlation with serum urea, a widely accepted marker of hydration. To our knowledge no such study was yet published. BIA/BIVA/BIS measurements of TBW and ICW explained a greater proportion of variability in urea levels than those from the BIA. Although the associations with serum creatinine were more mixed, the BIA/BIVA/BIS still demonstrated a marginally better overall concordance.

In terms of clinical classification, the BIA/BIVA/BIS identified a substantially higher number of dehydrated patients using TBW thresholds, and its classifications more frequently matched with biochemical indicators. This supports the hypothesis that more advanced BIA technologies, particularly those incorporating vector analysis and spectroscopy, may offer enhanced sensitivity in detecting fluid imbalances in clinical populations with abnormal physiology.

Similar findings, but without comparison to biochemical indicators, were published by Fassini *et al*. This observational study found that BIVA identified significant differences in hydration and soft tissue status between short bowel syndrome patients and matched controls, even when traditional bioelectrical impedance measures did not differ.[17] In patients with chronic kidney disease, Espinosa-Cuevas *et al*. demonstrated that BIVA showed good agreement with body composition and hydration parameters obtained using four different BIA technologies, particularly for the detection of fluid overload and post-dialysis changes in hydration status in hemodialysis patients.[18] Moreover, a narrative review on body composition assessment in athletes published in 2021 highlighted that BIVA provides greater accuracy in evaluating hydration status and body fluid changes compared with conventional BIA, which is limited by the lack of athlete-specific predictive equations.[19]

Interestingly, although more patients were identified as malnourished using the BIA/BIVA/BIS, the difference did not reach statistical significance. This may be due to the small sample size or the limitations of FFMI alone as a diagnostic criterion. Nevertheless, the observed trend supports the need for further investigation into the use of advanced BIA tools for nutritional risk screening.

Phase angle, a parameter derived directly from resistance and reactance, is considered a robust indicator of cellular integrity and prognosis.[20,21] In this study, phase angle-based classification of hydration showed greater agreement with BIA/BIVA/BIS. This is particularly relevant because phase angle is not reliant on predictive equations and is less affected by assumptions about body shape or hydration state[20], making it valuable in populations with abnormal fluid distribution, such as IF patients.

Limitations of this study include the single-time-point measurement and a relatively small sample size. Nonetheless, results suggest that the BIA/BIVA/BIS offers added value in monitoring hydration and nutritional status. Further research with a larger cohort and longitudinal design could validate these findings and support their application in broader clinical practice.

Conclusions

Our findings have practical implications for the routine monitoring of HPN patients. Given the challenges of accurately assessing hydration and nutritional status in this population, incorporating more sophisticated BIA tools like the BIA/BIVA/BIS could aid in early detection of dehydration and malnutrition, guide individualized therapy, and ultimately improve patient outcomes.

AI disclosure

During the preparation of this paper, the authors used Claude (Anthropic, Claude Opus 4.7) to improve the style and readability in some parts of the text. After using this tool/service, the authors have reviewed and edited the content as required and take full responsibility for the content of the publication.

Author contributions

TJ: Visualization; Validation; Writing – original draft; Writing – review & editing; **JO:** Formal analysis; Data curation; Investigation; Methodology; **NRK:** Conceptualization; Resources; Project administration; Supervision; Writing – review & editing.

References

1. Pironi L, Arends J, Baxter J, Bozzetti F, Peláez RB, Cuerda C, et al. ESPEN endorsed recommendations. Definition and classification of intestinal failure in adults. *Clin Nutr* 2015; **34:** 171-80. doi: 10.1016/j.clnu.2014.08.017

2. Nightingale J, Woodward JM; Small Bowel and Nutrition Committee of the British Society of Gastroenterology. Guidelines for management of patients with a short bowel. *Gut* 2006; **55(Suppl 4):** iv 1-12. doi: 10.1136/gut.2006.091108

3. O'Keefe SJ, Buchman AL, Fishbein TM, Jeejeebhoy KN, Jeppesen PB, Shaffer J. Short bowel syndrome and intestinal failure: consensus definitions and overview. *Clin Gastroenterol Hepatol* 2006; **4:** 6-10. doi: 10.1016/j.cgh.2005.10.002

4. Jeppesen PB. Spectrum of short bowel syndrome in adults: intestinal insufficiency to intestinal failure. *JPEN J Parenter Enteral Nutr* 2014; **38(1 Suppl):** 8S-13S. doi: 10.1177/0148607114520994

5. Lauverjat M, Hadj Aissa A, Vanhems P, Boulétreau P, Fouque D, Chambrier C. Chronic dehydration may impair renal function in patients with chronic intestinal failure on long-term parenteral nutrition. *Clin Nutr* 2006; **25:** 75-81. doi: 10.1016/j.clnu.2005.09.010

6. Pironi L, Arends J, Bozzetti F, Cuerda C, Gillanders L, Jeppesen PB, et al. ESPEN guidelines on chronic intestinal failure in adults. *Clin Nutr* 2016; **35:** 247-307. doi: 10.1016/j.clnu.2016.01.020

7. Forbes A, Shaffer J. Challenges in treating short bowel syndrome [Internet]. *ESPEN LLL Module* 2023; **12**. [cited 2026 Feb 15]. Available at: https://www.academia.edu/107516332/Challenges_in_treating_short_bowel_syndrome

8. Parrish CR, DiBaise JK. Short bowel syndrome in adults: part 3: hydrating the adult patient with short bowel syndrome. *Pract Gastroenterol* 2015; **39:** 10-8.

9. Pironi L, Boeykens K, Bozzetti F, Joly F, Klek S, Lal S et al. ESPEN guideline on home parenteral nutrition. *Clin Nutr* 2020; **39:** 1645-66. doi: 10.1016/j.clnu.2020.03.005

10. Vara-Luiz F, Glória L, Mendes I, Carlos S, Guerra P, Nunes G, et al. Chronic intestinal failure and short bowel syndrome in adults: the state of the art. *GE Port J Gastroenterol* 2024; **31:** 388-400. doi: 10.1159/000538938

11. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, et al. Bioelectrical impedance analysis – part I: review of principles and methods. *Clin Nutr* 2004; **23:** 1226-43. doi: 10.1016/j.clnu.2004.06.004

12. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, et al. Bioelectrical impedance analysis – part II: utilization in clinical practice. *Clin Nutr* 2004; **23:** 1430-53. doi: 10.1016/j.clnu.2004.09.012

13. Chambrier C, Normand S, Ecochard R, Pachiaudi C, Laville M, Boulétreau P. Total-body-water measurement with (18)O-labeled water in short-bowel patients with an ileostomy. *Nutrition* 2001; **17:** 287-91. doi: 10.1016/s0899-9007(00)00506-2

14. Bodystat Ltd. Bodystat Quadscan 4000 TOUCH brochure [Internet]. Bodystat; [cited 2025 Jul 1]. Available at: https://www.bodystat.com/content/Bodystat%20Quadscan%204000%20TOUCH%20BROCHURE.pdf

15. Bodystat Ltd. Bodystat Multiscan 5000 [Internet]. Bodystat; [cited 2025 Jul 1]. Available at: https://www.bodystat.com/product-catalog/bodystat-multiscan-5000

16. Cederholm T, Jensen GL, Correia MITD, Gonzalez MC, Fukushima R, Higashiguchi T, et al. GLIM criteria for the diagnosis of malnutrition - a consensus report from the global clinical nutrition community. *Clin Nutr* 2019; **38:** 1-9. doi: 10.1016/j.clnu.2018.08.002.

17. Fassini PG, Nicoletti CF, Pfrimer K, Nonino CB, Marchini JS, Ferriolli E. Bioelectrical impedance vector analysis as a useful predictor of nutritional status in patients with short bowel syndrome. *Clin Nutr* 2017; **36:** 1117-21. doi: 10.1016/j.clnu.2016.07.011

18. Espinosa-Cuevas A, Ch-Durán LX, Atilano-Carsi X, González-Ortiz A, Ramos-Acevedo S, López-Cisneros S, et al. Agreement between vector analysis and body composition measurements by four types of bioelectrical impedance technology in hemodialysis patients. *Nutr Hosp* 2022; **39:** 1047-57. doi: 10.20960/nh.04005

19. Campa F, Toselli S, Mazzilli M, Gobbo LA, Coratella G. Assessment of body composition in athletes: a narrative review of available methods with special reference to quantitative and qualitative bioimpedance analysis. *Nutrients* 2021; **13:** 1620. doi: 10.3390/nu13051620

20. Norman K, Stobäus N, Pirlich M, Bosy-Westphal A. Bioelectrical phase angle and impedance vector analysis--clinical relevance and applicability of impedance parameters. *Clin Nutr* 2012; **31:** 854-61. doi: 10.1016/j.clnu.2012.05.008

21. Khalil SF, Mohktar MS, Ibrahim F. The theory and fundamentals of bioimpedance analysis in clinical status monitoring and diagnosis. *Sensors (Basel)* 2014; **14:** 10895-28. doi: 10.3390/s140610895