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Review

Bioelectrical phase angle and impedance vector analysis – Clinical relevance and applicability of impedance parameters

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SUMMARY

Background & aims: The use of phase angle (PhA) and raw parameters of bioelectrical impedance analysis (BIA) has gained attention as alternative to conventional error-prone calculation of body composition in disease. This review investigates the clinical relevance and applicability of PhA and Bioelectrical Impedance Vector Analysis (BIVA) which uses the plot of resistance and reactance normalized per height.
Methods: A comprehensive literature search was conducted using Medline identifying studies relevant to this review until March 2011. We included studies on the use of PhA or BIVA derived from tetrapolar BIA in out- and in-patient settings or institutionalized elderly.
Results: Numerous studies have proven the prognostic impact of PhA regarding mortality or post-operative complications in different clinical settings. BIVA has been shown to provide information about hydration and body cell mass and therefore allows assessment of patients in whom calculation of body composition fails due to altered hydration. Reference values exist for PhA and BIVA facilitating interpretation of data.
Conclusion: PhA, a superior prognostic marker, should be considered as a screening tool for the identification of risk patients with impaired nutritional and functional status, BIVA is recommended for further nutritional assessment and monitoring, in particular when calculation of body composition is not feasible.

1. Introduction

For over 25 years, bioelectrical impedance analysis (BIA) has been in use for the estimation of body composition. BIA is a portable, easy-to-use, inexpensive and non-invasive method, which can be repeated frequently and is independent of patient cooperation. It measures whole-body impedance, the opposition of the body to alternating current consisting of two components: resistance (*R*) and reactance (*Xc*). Resistance is the decrease in voltage reflecting conductivity through ionic solutions. Reactance is the delay in the flow of current measured as a phase-shift, reflecting dielectric properties, i.e., capacitance, of cell membranes and tissue interfaces.[1,2] BIA is therefore not a direct method for assessment of body composition and its accuracy as an indicator of body composition relies largely on the use of appropriate regression equations. Body composition reference methods, such as isotope dilution or dual X-ray absorptiometry, have been used to generate the dependent variable for regression models. Various empirical equations for the calculation of body composition from BIA measurements of tissue impedance and reactance have thus been developed with considerable variation in the estimated body compartments.[3,4] Moreover, homogenous composition, fixed cross-sectional area and consistent distribution of current density are necessary assumptions for the correct estimation of body composition. In healthy subjects who have no fluid imbalance, no body shape abnormalities and who are within a certain BMI range (16–34 kg/m^2), BIA offers reliable information on body composition provided that suitable (i.e. age-, sex- and population-specific) equations for the calculation of body compartments are applied.[5]

However, these conditions are frequently violated in sick and hospitalized patients since disturbed hydration or altered distribution of extra- and intra-cellular water are often present, e.g., in liver cirrhosis, renal failure, cardiac insufficiency and obesity.[6–8]

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Therefore, the use of raw impedance parameter has gained attention. They provide information on hydration status and body cell mass and cell integrity without algorithm-inherent errors or requiring assumptions such as constant tissue hydration. They have moreover proven to be of prognostic value in various diseases.

This review outlines the clinical applicability of the most commonly used impedance parameter, the phase angle, and the combined use of reactance and resistance normalized by height in the *R*/*Xc* Graph using Bioelectrical Impedance Vector Analysis.

2. Phase angle

The most clinically established impedance parameter is the phase angle. It has gained popularity over the past years since it has shown to be highly predictive of impaired clinical outcome and mortality in a variety of diseases. It expresses both the amount and quality of soft tissue and can be calculated directly as its arc tangent: $(Xc/R) \times 180^{\circ}/\pi$. Phase angle has been suggested to be an indicator of cellular health[9,10] where higher values reflect higher cellularity, cell membrane integrity and better cell function. In healthy subjects phase angle usually ranges between 5 and 7°[11] but values above 9.5° can be reached in athletes.[12]

Phase angle indeed correlates with various indices of functional (e.g. $r = 0.53$ with grip strength in liver cirrhosis and $r = 0.4$ with knee extension strength and $r = 0.35$ with Barthel Index in elderly institutionalized subjects) and nutritional status (e.g. $r = 0.6$ with albumin, $r = 0.53$ with the Subjective Global Assessment)[13–17] and has early been suggested to be an index for muscularity.[15]

2.1. Determinants of phase angle

In healthy adults, age, sex and BMI are the major determinants of phase angle,[11,18] as shown in Table 1. Phase angle decreases with increasing age, due to a reduction in reactance which parallels the loss of muscle mass and an increase in resistance due to the declining proportion of body water at the expense of increasing fat mass in higher age. Men have higher phase angles than women due to the higher amount of body muscle mass. Moreover, phase angle increases with increasing BMI due to the increased number of muscle and fat cells. Interestingly, this association is only observed in BMI values <30 kg/m^2, in severely obese subjects with BMI >40 kg/m^2, an inverse correlation is found.[11] This has been attributed to higher tissue hydration due to fluid overload[19] or increased extracellular to intracellular water ratio of adipose tissue.[20] Moreover, physical activity appears to play a role, as shown in athletes[12,21] as well as in 60–90 year old healthy adults[13,18] where subjects in the highest quartiles of physical activity had higher phase angles. Since these studies did not investigate both muscle mass and physical activity it is tempting to speculate that the physical activity influences phase angle via a higher amount of muscle mass.

Table 1
Main determinants of phase angle.

	Authors
In healthy populations:	
Age	Bosy-Westphal et al.[11]
	Dittmar et al.[18]
	Barbosa-Silva et al.[33]
Sex	Bosy-Westphal et al.[11]
	Dittmar et al.[18]
	Barbosa-Silva et al.[33]
BMI	Bosy-Westphal et al.[11]
	Dittmar et al.[18]
Disease-specific parameters:	
Malnutrition	
Subjective Global Assessment	Maggiore et al.[29]
	Stobäus et al.[31]
Prealbumin	Avram et al.[92]
Inflammation	
C-reactive protein	Gunn et al.[13]
	Demirci et al.[25]
	Stobäus et al.[31]
Interleukin-6	Johansen et al.[26]

Although the reliability of BIA is high[18] one limitation regards measurement differences between BIA devices from different manufacturers.[22] Since there is no international manufacturing-standard, values from different devices differ which hampers direct comparison of results from different studies as well as the application of generally accepted reference values. Therefore, harmonization of technology as well as cross-calibration of the electrical resistors should be a mandatory future goal for impedance companies. Also, only BIA devices that can detect phase sensitive impedance variation indicate *Xc* and can be used for assessment of phase angle.

2.2. Phase angle in disease

Phase angle is frequently lower than normal in disease since influences such as infection, inflammation or disease-specific parameters may impair phase angle. Co-infection with tuberculosis and human immunodeficiency virus (HIV) was, for example, associated with significantly lower phase angles than HIV infection alone in one study. In these patients with pulmonary tuberculosis, there were no significant differences in BMI, or anthropometrically assessed fat and fat-free mass between HIV-positive and HIV-negative adults.[23] Among HIV-positive subjects, phase angles were significantly lower among those with CD4+ lymphocytes <200 cells/ml compared with those who had >200 cells/ml.[23] Lower phase angle values were found with volume overload or anaemia in heart failure patients[24] and volume overload and anuria in patients on peritoneal dialysis.[25] Repeated measurements during one year in patients on haemodialysis revealed decreasing phase angles whereas no significant changes in body weight, fat mass, lean body mass, or laboratory variables were observed.[26] In obese patients, women in the lowest phase angle tertile group revealed a significantly severe cardiovascular risk profile because their fat mass, glucose, interleukin 6, leptin and insulin resistance were significantly higher.[27] C-reactive protein, atherosclerosis parameters, albumin and creatinine correlated significantly with phase angle in peritoneal dialysis patients.[25]

Studies have reported various disease-specific determinants of phase angle. In patients on haemodialysis, creatinine and log soluble leptin receptor (sOB)/leptin ratio were significant independent predictors of phase angle next to age,[28] and higher interleukin 1 concentrations were associated with lower phase angles and with greater decrease of phase angle over time.[26] Maggiore and colleagues found serum albumin, age, mid arm muscle circumference, nutritional status according to Subjective Global Assessment (SGA) and normalized protein catabolic rate to be significant predictors for phase angle in haemodialysis patients.[29] In HIV infected men, insulin-like growth factor 1 was the only significant predictor in a multivariate analysis adjusted for number of drugs, disease severity age and nutritional intake.[30] We investigated determinants of phase angle in a large observational cross-sectional sample of hospitalized patients and found that weight loss and inflammation were independent predictors of phase angle next to age and sex. When studying the standardized phase angle (*Z*-score for patients' individual deviation of sex-, age-, and BMI-stratified mean reference values) only malnutrition and inflammation were identified as predictors of phase angle.[31]

2.3. Phase angle as indicator of nutritional status

When interpreting phase angle in sick populations, *R* and *Xc* must always be considered. Only if *R* is comparable between groups, the decrease of phase angle is due to the reduction of soft tissue and the phase angle might be seen as indicator of nutritional status.

Since phase angle is a marker of amount and quality of soft tissue mass as well as hydration status it has been considered a useful marker of nutritional status by many authors. In disease-related malnutrition, the characteristic early shift from intracellular to extracellular water and increased extracellular to body cell mass ratio[32] is reflected by the phase angle.[15] Not surprisingly, disease-related malnutrition has in fact been shown to be associated with altered electric properties of the tissue which are detectable with BIA.[17]

Several studies have corroborated this notion showing a close correlation between nutritional status and phase angle. One study in patients with benign gastrointestinal disease clearly showed a gradual decrease of the phase angle with progressing malnutrition determined with SGA.[17] Similarly, in the preoperative setting, phase angle was also closely correlated with the nutritional status determined with SGA[33] and in haemodialysis patients, phase angle exhibited a negative correlation with the SGA-1 score modified for renal disease.[14] In elderly nursing home residents[16] as well as in free living elderly,[34] impaired nutritional status defined by the Mini Nutritional Assessment was reflected by lower phase angle values. Phase angle also correlates well with biochemical markers such as albumin, total serum protein, creatinine, and blood urea nitrogen in patients[35] with renal disease and with measures of nutritional status such as total body protein and muscle mass in liver and renal disease.[14,15]

Underweight patients such as Anorexia Nervosa patients clearly have lower phase angles than well nourished subjects.[36] Moreover, phase angle appears to discriminate between different forms of underweight as shown by Marra et al.[21] When compared to normal weight controls, Anorexia Nervosa patients revealed significantly lower values ($5.09 \pm 0.52^{\circ}$), whereas ballet dancers ($6.40 \pm 0.51^{\circ}$) had significantly higher values reflecting their higher muscle mass and habitually lean subjects ($5.94 \pm 0.93^{\circ}$) did not differ from normal weight controls. Similarly, obese and overweight haemodialysis patients revealed lower phase angles than normal weight patients and BMI-matched controls which were associated with anthropometric measures of lean body mass and a higher protein catabolic rate.[37]

Improvement of nutritional status is also accompanied by an increase of phase angle. Studies in patients with Anorexia Nervosa reported a mean increase of 0.6° after 15 weeks of successful nutritional therapy,[38] and 1.1° in the stable refed state.[36] In malnourished patients with benign gastrointestinal disease, phase angle improved by $0.34 \pm 0.91^{\circ}$ after three month intervention with oral nutritional supplements.[39] Similarly, nutritional therapy improved phase angle in malnourished children (2.6 ± 2.6 years) as shown in small observational study. Interestingly, although the increase in body weight paralleled the increase in phase angle in these children, phase angle did not change in case of weight gain due to oedema.[40]

Despite the close correlation between nutritional status and phase angle, however, not all studies found the phase angle to be a reliable indicator of disease-related malnutrition. Gupta et al.[41] observed only modest sensitivities and specificities for different cut-offs of the phase angle when comparing it with the SGA in patients with advanced colorectal cancer. One study in haemodialysis patients likewise demonstrated that depending on cut-off values, the phase angle failed to reliably detect clinically relevant malnutrition (SGA C) although SGA was identified as one of the predictors of phase angle.[29]

This implies that valid cut-off values need to be identified in order to use the phase angle as clinical indicator for disease-related malnutrition in various disease settings. One approach is offered by percentiles of reference databases,[33,42] such as the reference values generated in a large cohort of healthy subjects that offers sex-, age- and BMI-stratified percentiles.[11] Standardizing phase angle according to the reference values provides an immediate measure for the patients' individual deviation from population norms.

2.4. Phase angle as indicator of functional status

As phase angle correlates with total body protein and muscle mass as well as hand grip strength,[43] it has been suggested to be a useful muscle index, thus also offering a qualitative, dynamic aspect of functional status.[15] Dittmar et al. demonstrated that elderly non-institutionalized men and women (60–90 years) with higher physical activity levels in household, sport, and leisure-time activities also exhibited significantly higher mean phase angle values.[18] Similarly, in elderly nursing home residents, we observed a significant relationship between phase angle and simple muscle function parameters such as hand grip strength and knee extension strength as well as Barthel Index of the activities of daily living.[16] In a large cohort of ambulatory rehabilitation patients, phase angle was also indicative of functional status, as patients with highest values in various functional measurements such as Timed Up and Go test, Functional Independence Measure and higher quadriceps strength also revealed significantly higher phase angle values, independent of sex.[13] In patients on haemodialysis, the level of spontaneous physical activity measured by number of daily steps taken correlated significantly with phase angle.[44]

In colorectal cancer patients, increase in phase angle was associated with an increase in physical and role function scales and likewise a decrease in fatigue of the European Organization for the Research and Treatment of Cancer questionnaire, indicating improved functional aspects of quality of life.[45]

2.5. Phase angle as prognostic indicator in disease

Given the close correlation between phase angle and nutritional as well as functional status it is not surprising that a high predictive potential of the phase angle – in particular with regard to mortality – has been reported by many studies.

Compared to healthy subjects, a low phase angle frequently occurs in sick patients correlating with disease severity.[13,15,23–25,44,46–55] It has consequently been shown to be predictive of impaired prognosis (mortality, disease progression, incidence of postoperative complications, length of hospital stay) in pancreatic,[56] colorectal,[57] breast and lung cancer,[58–60] as well as in HIV/AIDS,[61] liver cirrhosis,[15] renal insufficiency on peritoneal- or haemo-dialysis,[29,62] amyotrophic lateral sclerosis,[63] systemic sclerosis,[64] bacteraemia/sepsis[65] and surgical patients.[66] In HIV patients, phase angle was even the best single predictor of survival, superior even to CD4+ cell count.[67] Table 2 gives an overview on studies demonstrating the prognostic impact of low phase angle in various disease settings.

However, most authors generated phase angle cut-offs within their study population by using primarily the median or the lowest quartile or created cut-offs in comparison with a healthy control group. A major drawback of this method is that these cut-offs are not necessarily transferable to other populations and might thus not be applicable in the general clinical setting. Also, since these cut-off values do not consider determinants of phase angle, lower phase angle values cannot indiscriminately be attributed to

Table 2
Studies on prognostic impact of phase angle.

Study population	*N*	Cut-off value	BIA device	Clinical outcome of patients below cut-off value
HIV/AIDS				
HIV[67]	75	5.6°	101, RJL Systems	Decreased survival: parameter estimate in LR test: −0.799, $P < 0.0001$
HIV[61]	469	5.3°	2000-1, Data Input	Decreased survival: 463 days (95% CI: 397–528) vs. 697 (95% CI: 690–705), $P < 0.0001$ Increased progression of disease: 406 days (95% CI: 330–483) vs. 670 days (95% CI: 652–688), $P > 0.0001$
Tumour disease				
Lung cancer[60]	63	4.5°	101, RJL Systems	Decreased survival: OR = 1.25 (95% CI: 1.01–1.55), $P = 0.04$ - Stage IIIB: 3.7 vs. 12.1 months - Stage IV: 1.4 vs. 5.0 months
Colorectal cancer[57]	52	5.57°	101Q, RJL Systems	Decreased survival: 8.6 months (95% CI: 4.8–12.4) vs. 40.4 months (95% CI: 21.9–58.8), $P = 0.0001$ Increased mortality: RR = 10.75 (95% CI: 1.92–60.24; $P = 0.007$)
Pancreatic cancer[56]	58	5.08°	101Q, RJL Systems	Decreased survival: 6.3 months (95% CI: 3.5–9.2) vs. 10.2 months (95% CI: 9.6–10.8), $P = 0.02$ Reduction of RR 0.75 (95% CI: 0.58–0.96, $P = 0.02$) with every 1° increase in phase angle
Breast cancer[58]	259	5.6°	101Q, RJL Systems	Decreased survival: 23.1 months (95% CI: 14.2–31.9) vs. 49.9 months (95% CI: 35.6–77.8), $P = 0.031$ Reduction of RR 0.82 (95% CI: 0.68–0.99, $P = 0.041$) with every 1° increase in phase angle
Lung cancer[59]	165	5.3°	101Q, RJL Systems	Decreased survival: 7.6 months (95% CI: 4.7–9.5) vs. 12.4 months (95% CI: 10.5–18.7), $P = 0.02$ Reduction of RR 0.79 (95% CI: 0.64–0.97, $P = 0.02$) with every 1° increase in phase angle
Mixed tumours[93]	195	−1.65 SPA	101Q, RJL Systems	Increased 3 years mortality: RR = 2.35 (95% CI: 1.41–3.90, $P = 0.001$)
Mixed tumours[43]	399	5th percentile of reference values[11]	Nutriguard M, Data Input	Increased six month mortality OR = 4.0 (95% CI: 2.4–6.8; $P < 0.001$)
Dialysis				
Haemodialysis[29]	131	♂ 4.5° ♀ 4.2°	101, RJL Systems/Akern	Decreased 2 year survival rate (59.3% vs. 91.3%), $P < 0.01$ Increased mortality: RR = 2.6 (95% CI: 1.6–4.2), $P < 0.0001$
Haemodialysis[94]	3009	3.0° 3–4.0°	Quantum, RJL Systems	Increased mortality: RR = 2.2 (95% CI: 1.6–3.2, $P < 0.05$) RR = 1.3 (95% CI: 1.0–1.7, $P < 0.05$)
Peritoneal dialysis[35]	45	6.0°	101, RJL Systems	Decreased 1 year survival ($P = 0.01$)
Peritoneal dialysis[62]	48	6.0°	101, RJL Systems	Decreased 2.5 year survival ($P = 0.008$); RR = 0.39, $P = 0.027$
Peritoneal dialysis[92]	53	6.0°	101, RJL Systems	Decreased 5 year survival ($P = 0.004$); RR = 0.536, $P = 0.01$
Haemodialysis[53]	149	6.0°	101A, RJL Systems	Increased mortality RR = 4.12 (95% CI: 1.09–15.53; $P = 0.036$)
Other				
Liver cirrhosis[15]	305	5.4°	101, RJL Systems/Akern	Decreased 4.5 year survival, $P < 0.01$
Surgical patients[66]	225	−0.8 SPA	101Q, RJL Systems/Akern	4.3 fold increased risk of postoperative complication RR = 4.3 (95% CI: 1.6–11.8), $P = 0.02$
ALS[63]	168	2.5°	Analycor 3, Spengler	Decreased survival: 384 vs. 572 days, $P = 0.017$, HR = 0.80 (95% CI: 0.65–0.98), $P = 0.03$
Geriatric patients[95]	1071	3.5°	Nutriguard M, Data Input	4-fold increased hospital mortality of 20% (95% CI: 15–24%)
Heart failure[51]	41	Absolute	101, RJL Systems	Decreased survival (AUC = 0.86; 95%CI 0.72–1.0; $P = 0.01$)
Systemic sclerosis[64]	124	3.9°	Nutriguard M, Data Input	Decreased survival (61% vs. 98.8%), $P < 0.05$

LR = likelihood ratio; CI = confidence interval; OR = odds ratio; RR = relative risk.
SPA = standardized phase angle = (observed phase angle − mean of reference value/standard deviation of reference value).
ALS = Amyotrophic lateral sclerosis; HR = hazard ratio; AUC = area under the curve.

impairment of nutritional status as they can also be due to age or female sex. By contrast, reference values from a healthy population offer the possibility of assessing individual deviations of a patient in relation to the population average and percentiles of reference values might be used as cut-offs in the general clinical setting for the identification of patients at risk of impaired functional and nutritional status and increased mortality. Whereas several reference values have been published[11,33] only the reference values generated in a healthy German population ($n = 214{,}732$ adults)[11] are stratified according to sex, age, and BMI, which are established major determinants of the phase angle.

We recently demonstrated that the 5th phase angle percentile of sex-, age-, and BMI-stratified reference values is a simple and prognostically relevant cut-off in cancer patients suitable for the clinical setting.[43] Values below the 5th reference percentile clearly indicate impaired functional and nutritional status, decreased quality of life and increased 6-month mortality. The use of the 5th reference percentile therefore allows identification of patients who are in particular need of intensified medical and nutritional attention.

A new approach to the interpretation of the phase angle is its standardization according to reference values, i.e., creating a *Z*-score as follows: standardized phase angle = (observed phase angle − mean phase angle)/SD of the phase angle, where mean and SD are from reference values. This allows comparing values among patients differing in age, sex, BMI and disease. Also, since standardized phase angle values indicate individual deviations from the population, more complex and immediate information is gained than with a dichotomous cut-off variable (e.g. below or above the 5th reference percentile). Since the standardized phase angle is adjusted for age, sex and BMI, lower values indicate a true derangement of nutritional status or health status more reliably than absolute phase angle values.

We found that the standardized phase angle was a significant predictor for malnutrition and impaired functional status as well as

a superior indicator of 6-month survival than malnutrition and disease severity in cancer patients.[43]

3. Bioelectrical impedance vector analysis for assessment and monitoring of hydration and nutritional status

The bioelectrical impedance vector analysis (BIVA) approach developed by Piccoli et al.[68] uses the plot of the impedance parameters resistance (*R*) and reactance (*Xc*) normalized per height as a bivariate vector in the *RXc* graph. The normalization for height allows for the length of the conductor and thus provides a qualitative measure of soft tissue that does not depend on body size. The position and length of the vector provides information about hydration status, body cell mass and cell integrity. A migration sideways of the vector due to low or high reactance indicates decrease or increase of dielectric mass (membranes and tissue interfaces) of soft tissues. The length of the vector indicates hydration status from fluid overload (decreased resistance, short vector) to exsiccosis (increased resistance, longer vector)[68,69] (see Fig. 1). If groups of patients are portrayed in the *RXc* graph as mean vector, the vector distribution is described by its associated 95% confidence interval (confidence ellipse). Significant vector displacement is seen with increasing disease severity,[70,71] in obesity,[37] disease-related malnutrition[16,17] and fluid removal during dialysis.[8,72,73]

The BIVA approach has gained attention as a tool to assess and monitor patients' hydration and nutrition status in patients on haemodialysis[8,72–74] or continuous ambulatory peritoneal dialysis,[75] liver cirrhosis,[76] critically ill patients[77] and obese patients with stable and changing weight[78] since it is independent of disputable regression equations for calculation of lean body mass and fat mass as well as independent of measurement of body weight.

Comparison to reference values is moreover possible in BIVA; individual vectors can immediately be ranked in regard to tolerance ellipses representing 50%, 75% and 95% of reference values, which allows a detailed classification of vector position. Healthy subjects are usually positioned within the 75th tolerance ellipse.[79] Sex-, age-, and BMI-stratified reference values from a German population[80] are available as well as US reference values stratified according to sex, age and ethnicity.[42]

3.1. BIVA in comparison to phase angle

BIVA thus enables a more detailed understanding of hydration status and cell mass compared to phase angle alone. Since phase angle is calculated from reactance and resistance, different positions of the vector in the *RXc* Graph can theoretically produce identical phase angles (see Fig. 1). Differentiation between obese (high phase angle, short vector) and athletic subjects (high phase angle and long vector) is consequently possible with BIVA just as discrimination between cachectic (low phase angle and long vector) and lean subjects (normal phase angle and long vector) Longitudinal changes in hydration and cell mass can therefore be interpreted more reliably by BIVA than phase angle, which makes BIVA a valuable tool for assessment and monitoring of patients. For monitoring, high reproducibility is required. Within-day variability of whole-body impedance has been shown to be small in healthy populations.[18,81] When BIA measurements are carried out according to standardized protocols in sick patients,[82] inter-rater variability is very low as shown by low coefficients of variance $\leq$3% for *R* and *Xc*.[43,83] Since minimal detectable changes depend on the precision of the method, BIVA qualifies as monitoring tool.

3.2. BIVA as measure of hydration

BIVA has been well investigated for the evaluation of hydration status. In patients with renal insufficiency in particular, BIVA has shown to be an effective method to assess hydration status[84] and identify patients with a critical fluid overload[73] which is associated with increased risk of mortality. Pillon et al. demonstrated that shorter vector length as a measure of inadequate ultrafiltration was associated with increased mortality, and that the increase in relative risk with shorter vector length was independent of age, sex, ethnicity, diabetes, length of time on dialysis, albumin, creatinine, haemoglobin, ferritin, and even phase angle.[85] In critically ill,

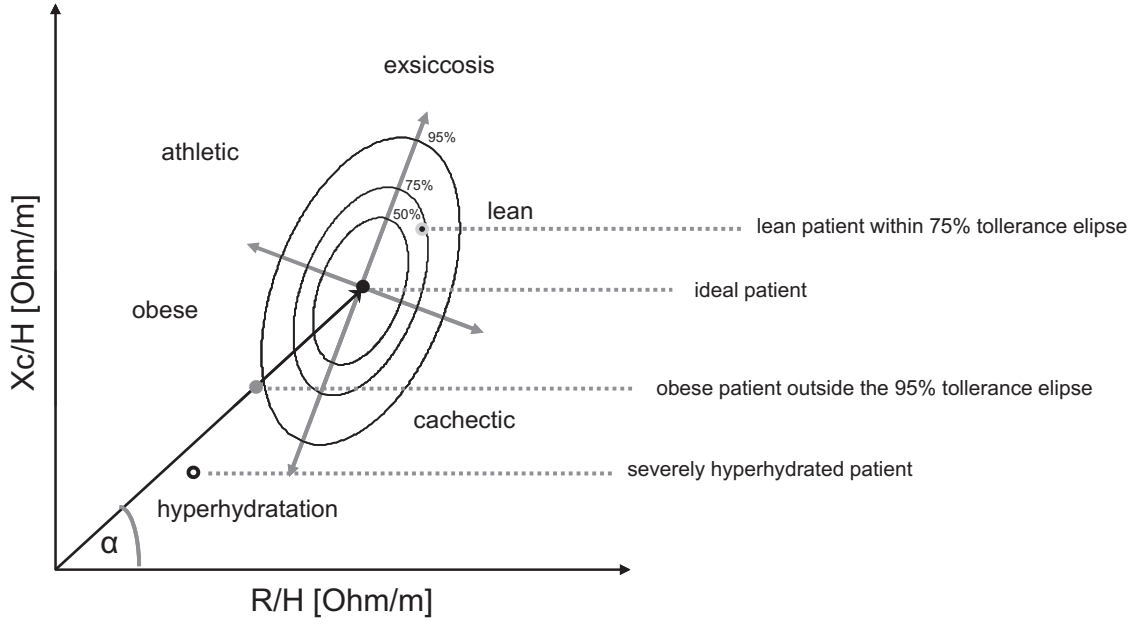

Fig. 1. Different positions of the vector in the *RXc* graph indicating different body composition can theoretically produce comparable phase angles (α). Longitudinal changes in hydration and cell mass are therefore interpreted more reliably by BIVA than phase angle alone.

central venous pressure correlated more closely with direct impedance measurements than with calculated total body water. Shorter impedance vectors reliably indicated overhydration in patients with central venous pressure values >12 mmHg.[77] Also, fluid removal during haemodialysis can be monitored in the *RXc* graph.[8] In obese uraemic patients, weight loss due to fluid loss was reflected by a lengthening of the impedance vector, which was not seen when weight loss was due to calorie restriction in the obese control group.[78] During pregnancy and post partum, BIVA has been shown to be a valid method to monitor changes in total body water and identify women with excessive fluid gain when compared to isotope dilution.[86]

In peritoneal dialysis, it has been proposed that segmental bioimpedance measurements of the thoracic region provide more relevant information of the fluid changes than whole-body impedance.[73] Indeed, overhydrated patients with an increased risk for cardiovascular disease were more accurately identified.[73] Similarly, overhydration in hypertensive haemodialysis patients was identified with segmental thoracic measurements.[87]

3.3. BIVA as measure of nutritional status

In healthy elderly, impedance vectors clearly indicate the age associated reduction of soft tissue, particularly after the age of 80. *Xc*/*H* and phase angle decrease with age in both men and women.[88] In patients with Alzheimer disease, mean vector position was significantly different in the patients with mild-moderate Alzheimer disease with respect to controls, indicating lower soft tissue.[89] Women with severe Alzheimer disease also showed both reduced tissue mass and dehydration when compared with patients with mild–moderate disease severity.[89]

The mean impedance vectors from patients with heart failure in the NYHA III–IV group were significantly shorter and more downsloping than those in the NYHA I–II group, indicating a progressive increase in soft tissue hydration with increasing disease severity.[71]

Ongoing weight loss common in malnutrition has a distinct effect on electric properties of the tissue which is not seen in underweight classified by BMI. In patients with benign gastrointestinal disease, a significant mean vector displacement is seen in severe malnutrition compared to both well nourished and moderately malnourished patients.[17]

When categorizing the patients according to their BMI, however, the mean vector of the BMI groups migrated in the opposite direction of the mean vector of the SGA groups, when going from the high BMI category (>30 kg/m^2) to the low BMI category (<18.5 kg/m^2). The vector migration of the BMI groups is consistent with the vector migration shown in a retrospective analysis of the large NHANES databank by Piccoli et al.[42] as well as reference data by Bosy-Westphal et al.[80] with both *R*/*H* and *Xc*/*H* components actually decreasing with increasing BMI. Comparing underweight patients (BMI < 18.5 kg/m^2) and weight-losing patients (median BMI 19.4 kg/m^2, SGA C), we even observed significantly lower *R*/*H* and *Xc*/*H* values in the malnourished patients despite comparable BMI and phase angle between these groups, which resulted in different vector positions. These results imply that malnutrition defined by the SGA is associated with altered tissue structure as well as loss of body mass whereas these altered electric properties of the tissue are not seen in simple underweight according to BMI. These findings moreover show that vector analysis provides a better understanding of whole-body impedance than phase angle alone since phase angle is sensitive to hydration.

In nursing home residents[16,90] or free living elderly,[34] a mean vector displacement was also observed between well nourished and moderate or severely malnourished subjects assessed with the Mini Nutritional Assessment. Also, vector migration due to both increasing *Xc*/*H* and decreasing *R*/*H*, indicating greater cell mass, was reflected by increased hand grip strength.[91]

In conclusion, bioelectrical phase angle and BIVA represent a clinically feasible approach to body composition, free from equation inherent errors and necessary assumptions, although quantities of body compartments are not measured. While this might make BIA less attractive for some research purposes, the evaluation and identification of patients by BIVA (Fig. 1) might be used as screening tool for the development of inclusion and exclusion criteria for clinical studies. Phase angle has been shown to be a superior indicator of survival and outcome and should therefore be used as screening tool for identification of patients at risk because of impaired nutritional or functional status. BIVA provides more detailed information on hydration and cell mass integrity and should therefore be considered as an assessment and monitoring tool.

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Statement of authorship

The authors' responsibilities were as follows – KN, NS: literature research and writing of the manuscript; and AB-W and MP: critical input and revision of the manuscript.

Conflict of interest

The authors declare that they have no financial conflict of interest.

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