Bio-impedance in evaluation of volume status in peritoneal dialysis patients

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Volume overload in patients with End Stage Renal Failure

- In patients with ESRD, cardiovascular diseases are the leading cause of mortality, and fluid overload has an important role in the development of these diseases.

- In patients receiving PD, fluid retention can be intensified over time due to the loss of residual kidney function and progressive muscle wasting.

- As clinical signs in evaluation of fluid status may be misleading, more reliable practical methods are extremely needed.

- Bio-imedance analysis (BIA) is a simple, safe, noninvasive, rapid , and promising method which can be used to determine hydration status of patients with ESRD.

Bio-impedance analysis in peritoneal dialysis

- Assessment of body composition
- Estimation of of nutritional status
- Management of extracellular fluid

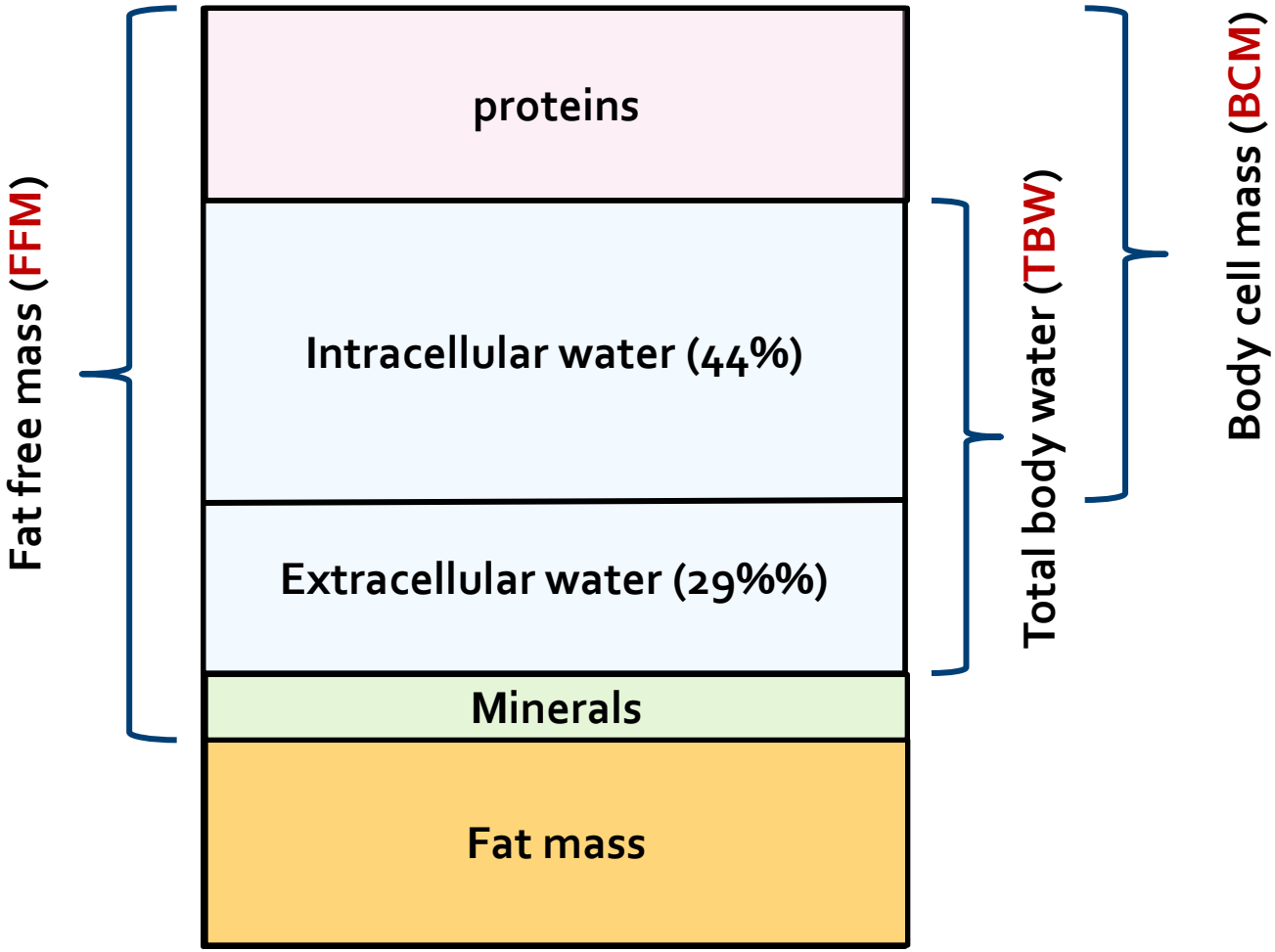
Historical background of Bio-impedance

- Electrical properties of tissues was firstly described by Hermann in 1871.
- About a hundred year later, Thomasset conducted the original studies using electrical impedance measures as an index of total body water.
- A variety of single frequency analyzers then became commercially available.
- By 1990, several multi-frequency analyzers were also be presented in the market.

Machines for bio-impedance analysis

- Quantum II (RLJ System)
- SC-331 S (Tanita Corporation
- ElectroFluidGraph (Akern s.r.l.)
- SFB7 (Impedimed Ltd.)
- Bioscan 916S (Maltron Ltd.
- Body Composition Monitor (Fresenius Medical Care)

Body composition



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NEPHROLOGY – ORIGINAL PAPER

Value of bioimpedance analysis estimated "dry weight" in maintenance dialysis patients: a systematic review and meta-analysis

Adrian Covic[1] · Adi-Ionut Ciumanghel[1] · Dimitrie Siriopol[1] · Mehmet Kanbay[2] · Raluca Dumea[1] · Cristina Gavrilovici[3] · Ionut Nistor[1,4]

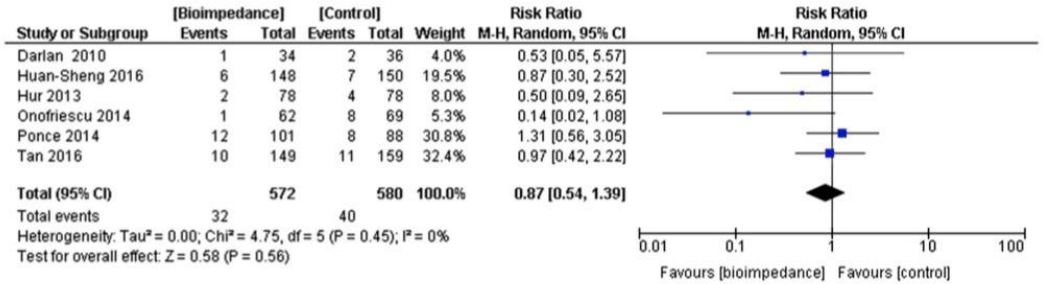


Fig. 3 Forest plot for all-cause mortality

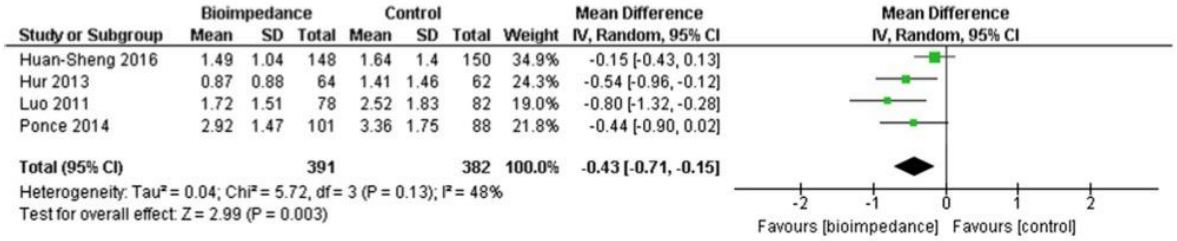


Fig. 4 Forest plot for change in overhydration (L)

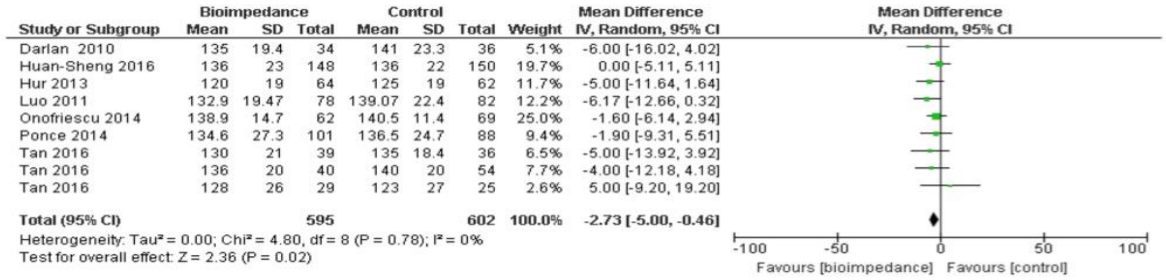
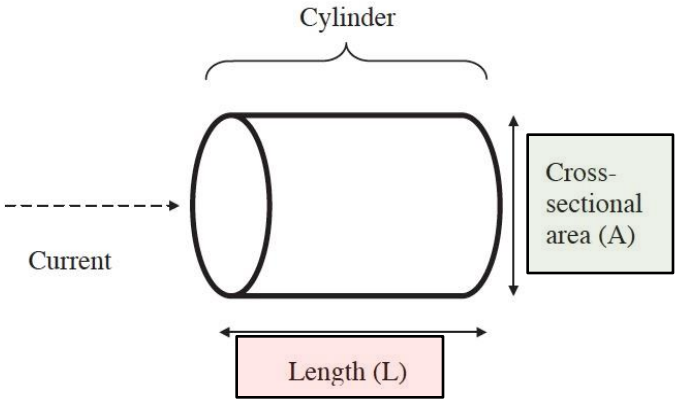


Fig. 6 Forest plot for systolic blood pressure control

- Seven RCTs with 1312 patients included.
- Applying the results of BIA in fluid management did not reduce all cause mortality. However, it improved systolic blood pressure and hydration status

Principles of Bio-impedance



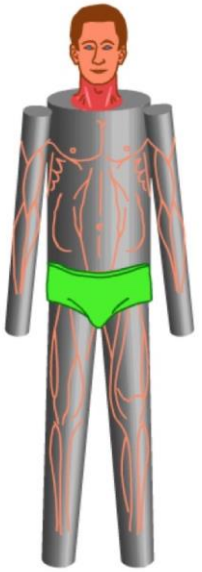
- In a uniform cylinder of conductive material, the resistance (R) to an electrical current is proportional to its length (L) and inversely proportional to its cross sectional area (A).

- $R = \rho L/A$ ρ : resistivity of a conductive material
  $R = \rho L/A = \rho L^2/AL$ (the fraction multiplied by an L/L fraction) ,
  Volume of a cylinder=height X area= LXA, $R = \rho L^2/V$

- The volume of a cylinder can be calculated by this formula: $V = \rho R/L^2$

- So, there is an empirical relationship between lean body mass(73% water) and R/L^2

Cylinder model in Bio-impedance analysis

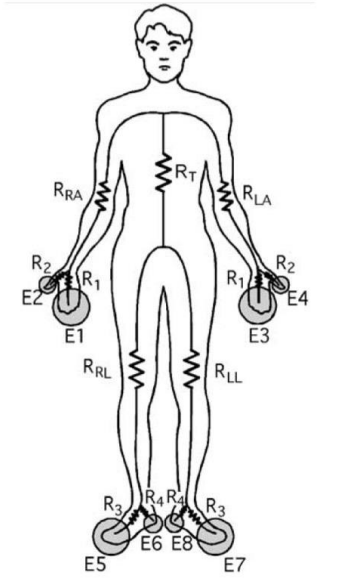


- Shorter and thicker segments contribute less to the total R.
  (body impedance is determined by limbs up to 90% and by trunk up to 10%)
- In practice, it is easier to measure height than conductive length, which is from wrist to ankle.
- As the body is not a homogenous cylinder, the term height^2 /R should be matched to the real geometry by an appropriate coefficients and fitting factors.

Example equation to determine total body water:

$$TBW = 0.372\frac{Ht^2}{R} + 3.05Gender(0\ for\ female, 1\ for\ male) + 0.142Weight - 0.069Age$$

Lukaski and Bolonchuk, Aviation Space and Environmental Medicine ***59*** *1163-1169, 1988)*



European Journal of Clinical Nutrition 63, 619-626 (May 2009)

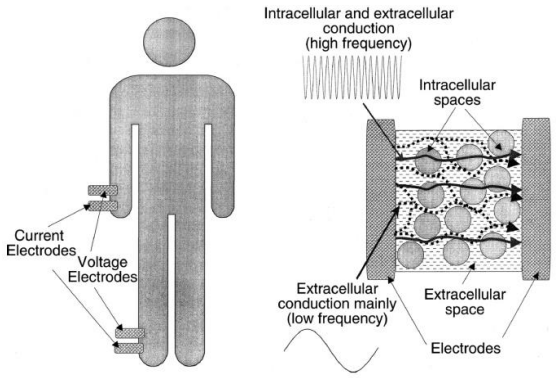
Errors of bio-impedance analysis based on cylindrical model

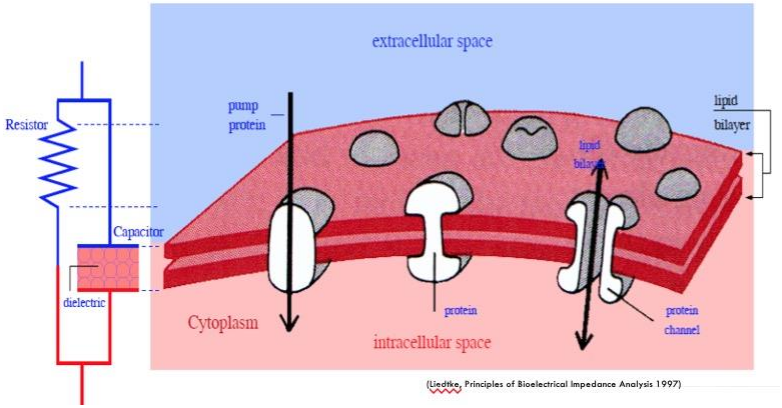
- Alternations in resistivity and conductive material
- Variations in the ratio of height to conductive length
- Variations in the shape of the body

Our body offers two type of resistance to an electrical current

- Resistance or R, arising from intracellular and extracellular fluids (simply called resistance)

- Capacitance or X_C , arising from cell membranes (reactance)



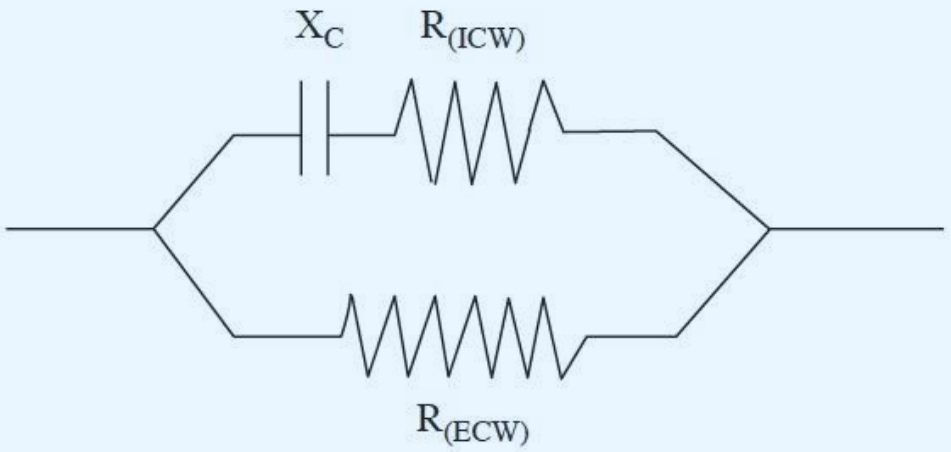


Impedance

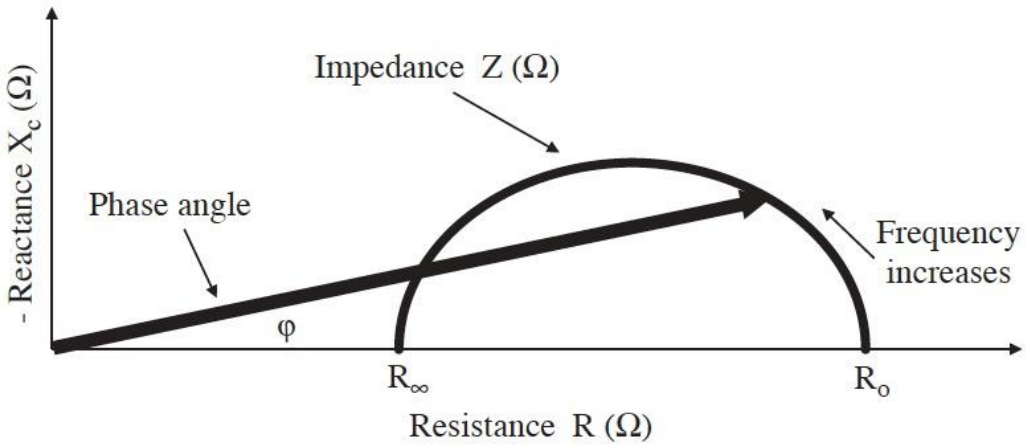
is a term used to describe the combination of resistance and capacitance

A commonly used circuit to describe the behavior of biologic tissues in the body

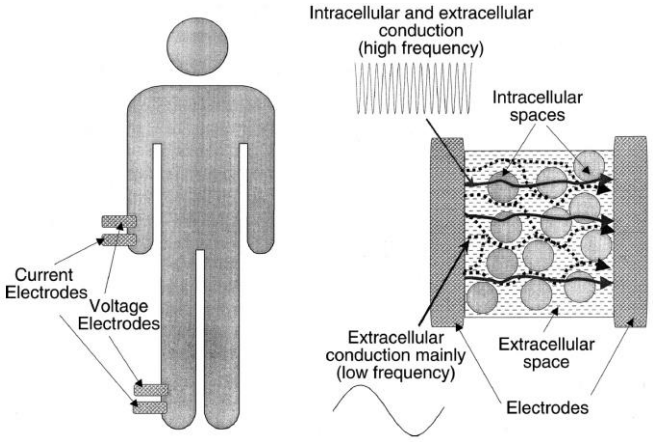
Fricke's circuit
Two parallel electrical conductors:
$R_{(ECW)}$: H_2O-Na
$R_{(ICW)}$: H_2O-K
isolated by a cell membrane (X_c)



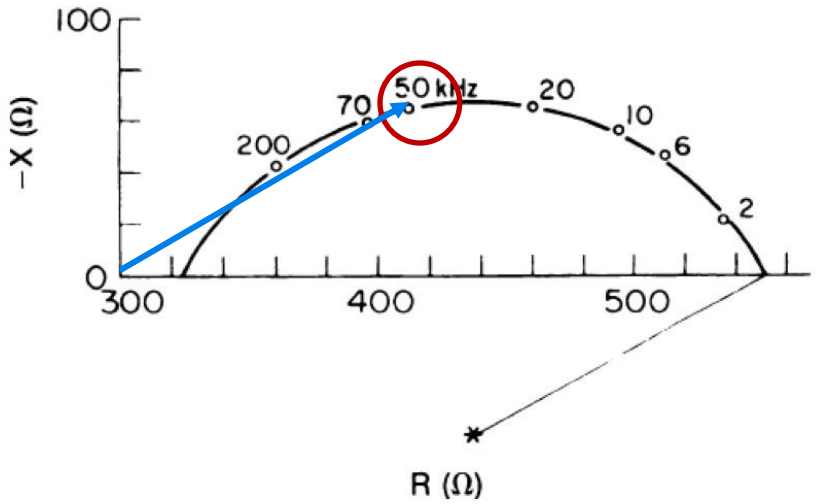
SF-BIA	Single Frequency Bioelectrical Impedance Analysis
MF-BIA	Multi Frequency Bioelectrical Impedance Analysis
BIVA	Bioelectrical Impedance Vector Analysis
BIS	Bioelectrical Impedance Spectroscopy
W-BIA	Whole Body Bioelectrical Impedance Analysis
S-BIA	Segmental Bioelectrical Impedance analysis



Phase angle and its relationship with impedance, resistance, reactance, and the frequency of applied current



Zero frequency: the current passes through extracellular fluid,
Infinite frequency: total body R reflects the combination of intracellular and extracellular fluid.



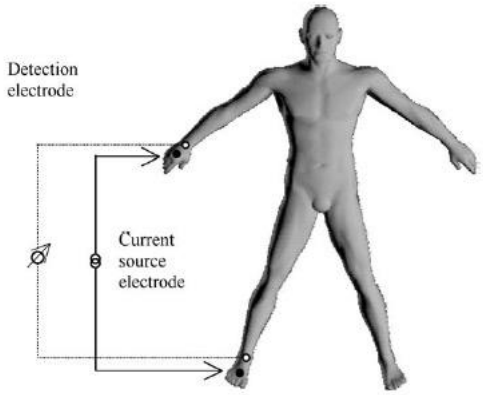
American Journal of Clinical Nutrition 1996; 64: 388S-96S

Most single frequency BIA(SF-BIA) analyzers operate at 50kHz.
Multi-frequency BIA(MF-BIA) uses different frequencies.

SF-BIA

- An alternative current of 50 kHz and 800 μA is passed between surface electrodes placed on wrist and ankle.

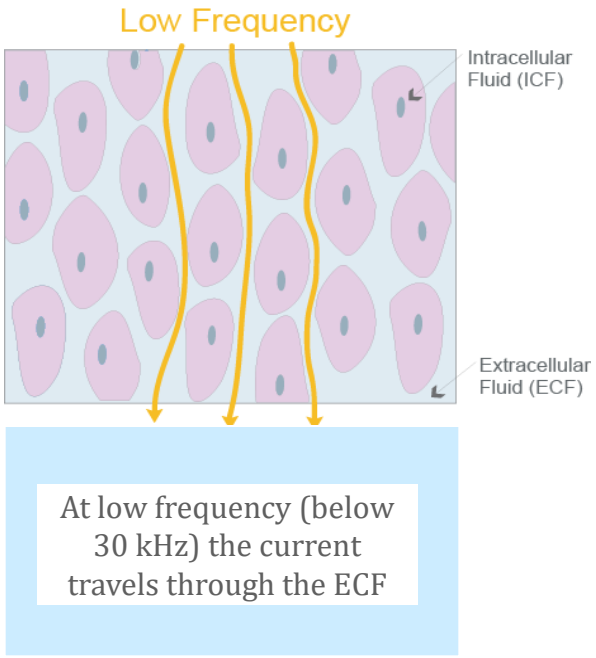
- At 50 kHz, the current passes through both intra and extracellular fluid.



M-BIA

- As with SF-BIA, MF BIA uses linear regression models but include impedance at multiple frequency to evaluate FFM, TBW, ICW, and ECW.

- MF-BIA can be more accurate and less biased than SF-BIA for the prediction of ECF.



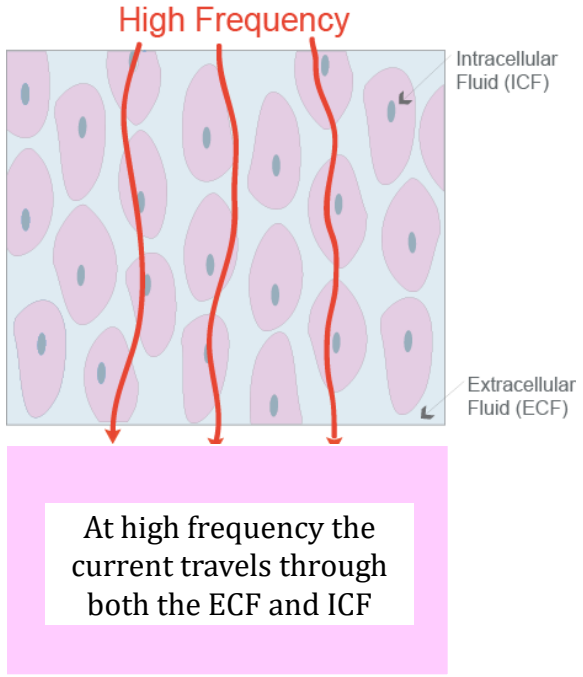


Table 4 Bioelectrical impedance analysis equation reported in the literature since 1990 for extracellular water (ECW), classified according to standard error of the estimate (SEE).

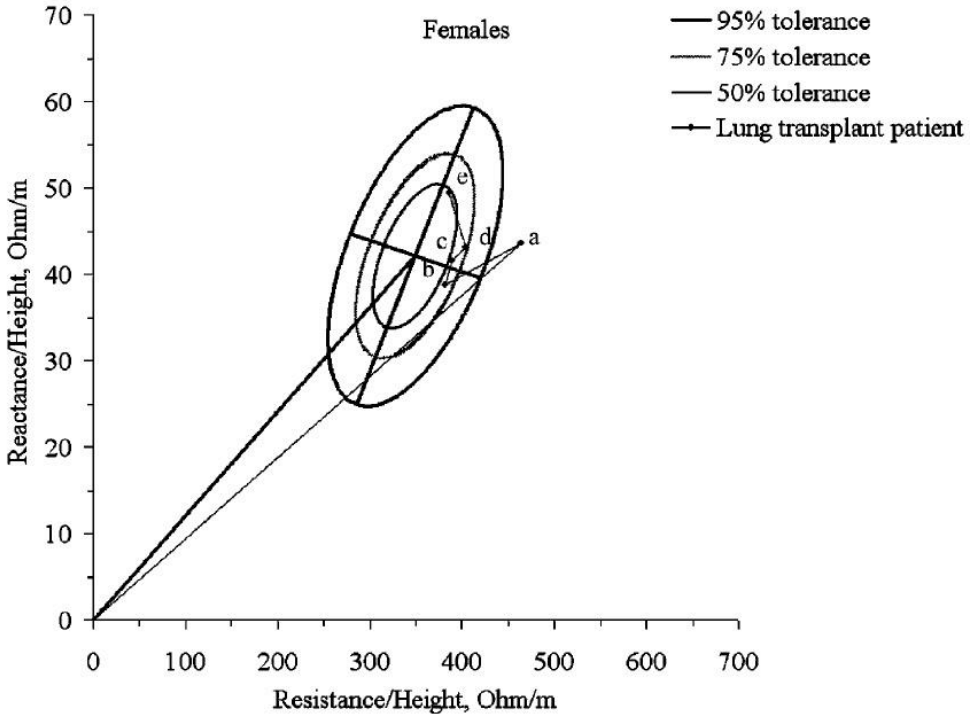
Population	Source	n	Criterion measure	Equation	r^2	SEE	BIA instrument
Healthy subjects	Deurenberg et al.[90]	139	KBr	$2.30 + 0.19528\,Ht^2/Z_1 + 0.06987\,weight - 0.02\,age$	0.87	0.98	Human-IM
Healthy subjects	Deurenberg et al.[90]	139	KBr	$2.53 + 0.18903\,Ht^2/Z_5 + 0.06753\,weight - 0.02\,age$	0.86	1.02	scanner
Healthy subjects, 19–65 yr	Van Loan and Mayclin[92]	60	NaBr	$-5.17753 + 0.09989\,Ht^2/R_{224} + 0.09322\,weight - 1.3962\,sex(men = 0, women = 1)$	0.92	1.06	Xitron
Healthy[22] and ill subjects[18]	Sergi et al.[95]	40	NaBr	$-7.24 + 0.34\,Ht^2/R_1 + 0.06\,weight + 2.63(healthy = 1, ill = 2) + 2.57\,sex(men = 0, women = 1)$	0.89	1.75	RJL-101 and 103
Healthy[22] and ill subjects[18]	Sergi et al.[95]	40	NaBr	$-5.22 + 0.20\,Ht^2/R_{50} + 0.005\,Ht^2/Xc_{50} + 0.08\,weight + 1.9(healthy = 1, ill = 2) + 1.86\,sex(men = 0, women = 1)$	0.89	1.75	
Healthy non-obese and obese subjects	Cox-Reijven and Soeters[32]	90	NaBr	$-3.511 + 0.351\,Ht^2/R_{ecw} + 0.05\,weight$	0.77	2.0	Xitron
Healthy subjects	Cornish et al.[25]	60	NaBr	$-6.3 + 0.352\,Ht^2/R_0 + 0.099\,weight + 3.09\,sex(0 = male, 1 = female)$	0.7	2.1 or 11.7%	SEAC
Healthy subjects	Cornish et al.[25]	60	NaBr	$1.2 + 0.194\,Ht^2/R_0 + 0.115\,weight$	0.65	2.2 or 12.7%	SEAC
Healthy subjects	Cornish et al.[25]	60	NaBr	$-5.3 + 0.480\,Ht^2/R_0 + 3.5\,sex(0 = male, 1 = female)$	0.66	2.2 or 12.6%	SEAC
Elderly, 63–87 yr	Visser et al.[93]	117	KBr	$Men = 4.8 + 0.2249\,Ht^2/Z_5$	0.39	2.2	Xitron
				$Women = 1.7 + 0.1998\,Ht^2/Z_5 + 0.0571\,weight$	0.65	1.0	
Surgical patients	Hannan et al.[20]	43	NaBr	$5.75 + 0.01\,Ht^2/Xc_{50} + 0.165\,Ht^2/R_5$	0.87	1.7	Xitron
Surgical patients	Hannan et al.[20]	43	NaBr	$6.15 + 0.0119\,Ht^2/Xc_{50} + 0.123\,Ht^2/R_{50}$	0.87	1.7	Xitron

BIA equations are shown in order of increasing standard error of the estimate (SEE). They are limited to studies in healthy subjects that include at least 40 subjects and are validated against a criterion measure.

R, resistance; Ht^2/R, height^2/resistance; R_{ecw}, Resistance by Cole–Cole plot; Xc, reactance; V, body volume; Z, impedance; Z_5, impedance at 5 kHz; Z_{100}; impedance at 100 kHz; 1 for men, 0 for women, unless otherwise stated.

NaBr = sodium bromide, KBr = Potassium bromide.

Human-IM Scanner, Dietosystem, Milan, Italy; Xitron Technologies, San Diego, CA; RJL Systems, Inc, Clinton Twp, MI; SEAC, Brisbane, Australia.



BIVA: bioelectrical vector analysis

By graphical plotting of R and capacitance after standardized by height different conditions can be diagnosed

Movements parallel to minor access and major access of tolerance ellipse indicate changes in nutritional and hydration status, respectively.

In a study by Yilmaz et al., OH/ECW ratio, a derived parameter of fluid overload measured by BIA, was a significant and independent determinant of systolic blood pressure and left ventricular mass index in PD patients.
(OH: overhydration)

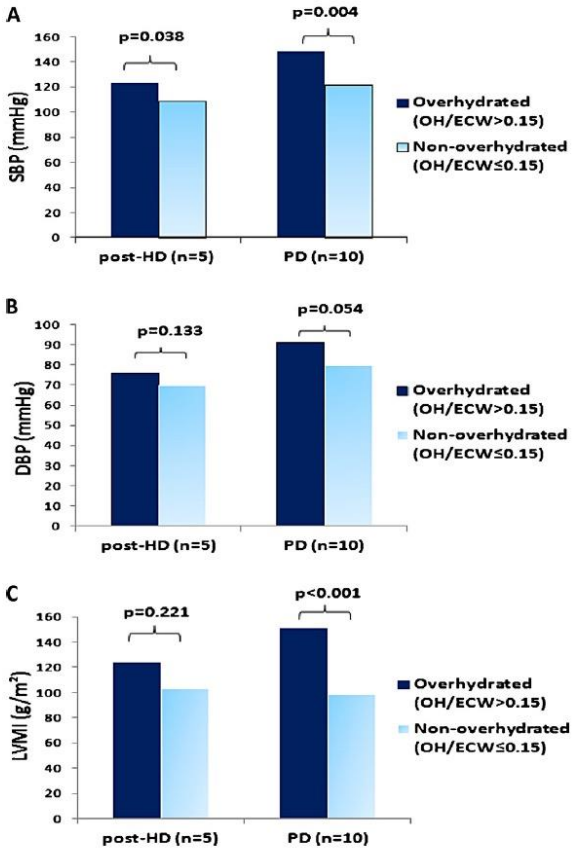


Fig. 1 – Comparison of systolic blood pressure (SBP) (A), diastolic blood pressure (DBP) (B), and left ventricular mass index (LVMI) (C) between overhydrated and nonoverhydrated patients in posthemodialysis (post-HD) and peritoneal dialysis (PD) groups.

Parameters	post-HD ($n = 43$)	PD ($n = 33$)	P
Age, years	51.8 ± 15.8	38.6 ± 15.8	0.001
Gender, M/F, *n*	13/30	11/22	0.77
Dialysis vintage, months (months)	70.6 ± 39.8	75 ± 51.5	0.79
Diabetes, %	25.6	3	0.008
Residual urine, mL/day	29 ± 9	479 ± 70	0.001
Na, mEq/L	136 ± 2	135 ± 2	0.131
Albumin, g/dL	3.3 ± 0.4	3.1 ± 0.4	0.202
Hemoglobin, g/dL	10.9 ± 1.4	12.8 ± 16.6	0.335
SBP, mmHg	111 ± 14	129 ± 24	<0.001
DBP, mmHg	71 ± 9	83 ± 15	<0.001
OH, L	0.6 ± 1.0	1.3 ± 1.2	0.011
TBW, L	28.5 ± 6.9	27.4 ± 5.7	0.52
ECW, L	13.2 ± 3.1	13.4 ± 2.8	0.95
ICW, L	15.2 ± 4.3	14.4 ± 3.0	0.34
ECW/ICW	0.9 ± 0.1	0.9 ± 0.1	0.35
ECW/TBW	0.4 ± 0.05	0.4 ± 0.08	0.23
OH/ECW	0.04 ± 0.07	0.09 ± 0.09	0.009
OH/ECW >0.15, %	11.6	30.3	0.043
LVEF, %	66 ± 4	59 ± 0.8	<0.001
LVMI, g/m^2	106 ± 24	113 ± 33	0.31

SBP, systolic blood pressure; DBP, diastolic blood pressure; OH, overhydration; ECW, extracellular water; ICW, intracellular water; TBW, total body water; LVMI, left ventricular mass index; LVEF, left ventricular ejection fraction; post-HD, posthemodialysis; PD, peritoneal dialysis.

Kidney International, Vol. 65 (2004), pp. 1050–1063

DIALYSIS – TRANSPLANTATION

Bioelectric impedance vector distribution in peritoneal dialysis patients with different hydration status

ANTONIO PICCOLI, FOR THE ITALIAN CAPD-BIA STUDY GROUP

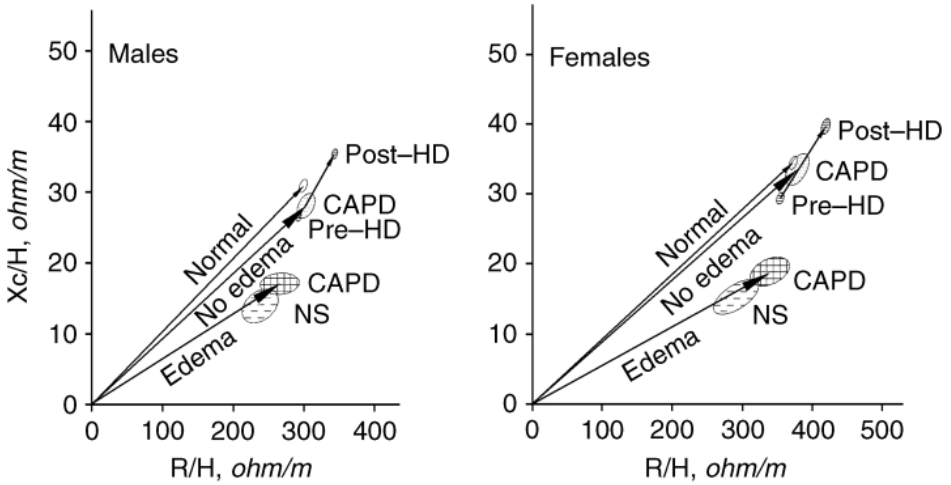
Department of Medical and Surgical Sciences, Nephrology Clinic, University of Padova, Padova, Italy

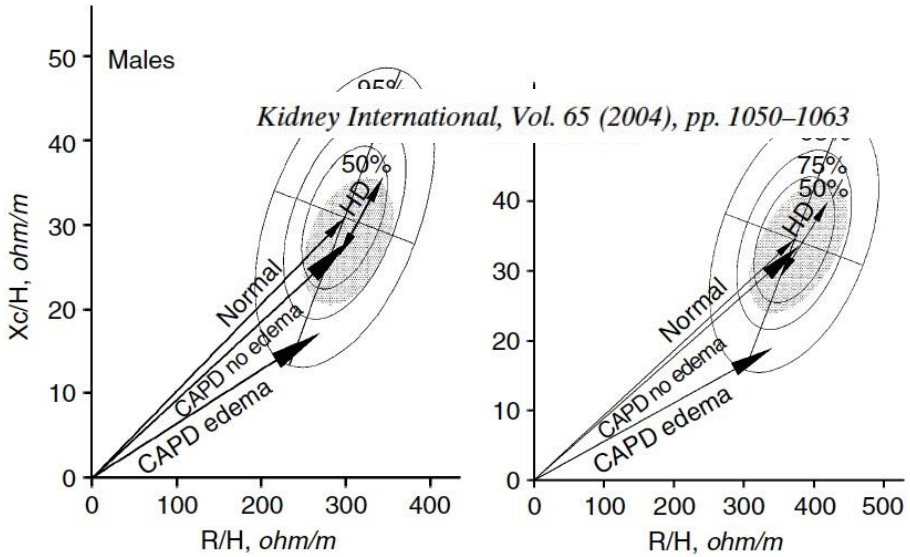
SF-BIA results of 200 CAPD adults patients (149 without and 51 with edema) were compared with the results of the following groups:

726 Healthy subjects

1116 Hemodialysis patients

50 Nephrotic patients





The mean impedance vector of CAPD patients without edema was half way between the mean vectors of the healthy population and the HD patients before the hemodialysis session.

Kidney International, Vol. 65 (2004), pp. 1050–1063

Longitudinal bioimpedance vector plots add little value to fluid management of peritoneal dialysis patients

Boon K. Tan[1,2,6], Zanzhe Yu[1,3,6], Wei Fang[3], Aiwu Lin[3], Zhaohui Ni[3], Jiaqi Qian[3], Graham Woodrow[4], Sarah B. Jenkins[5], Martin E. Wilkie[5] and Simon J. Davies[1,2]

[1]Institute for Science and Technology in Medicine, Keele University, Keele, UK; [2]Department of Nephrology, University Hospitals of North Midlands, Stoke-on-Trent, UK; [3]Department of Nephrology, Renji Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China; [4]Department of Nephrology, Leeds Teaching Hospitals, Leeds, UK; and [5]Department of Nephrology, Sheffield Northern General Hospital, Sheffield, UK

- Study design: blind randomized control trial
- Participants: 308 PD patients from the UK and Shanghi, recruited into 4 groups according to country and residual renal function.
- Objective: to test the hypothesis that whether the longitudinal application of BIA alongside clinical evaluation would help the clinician to make appropriate adjustment in fluid management of PD patients.

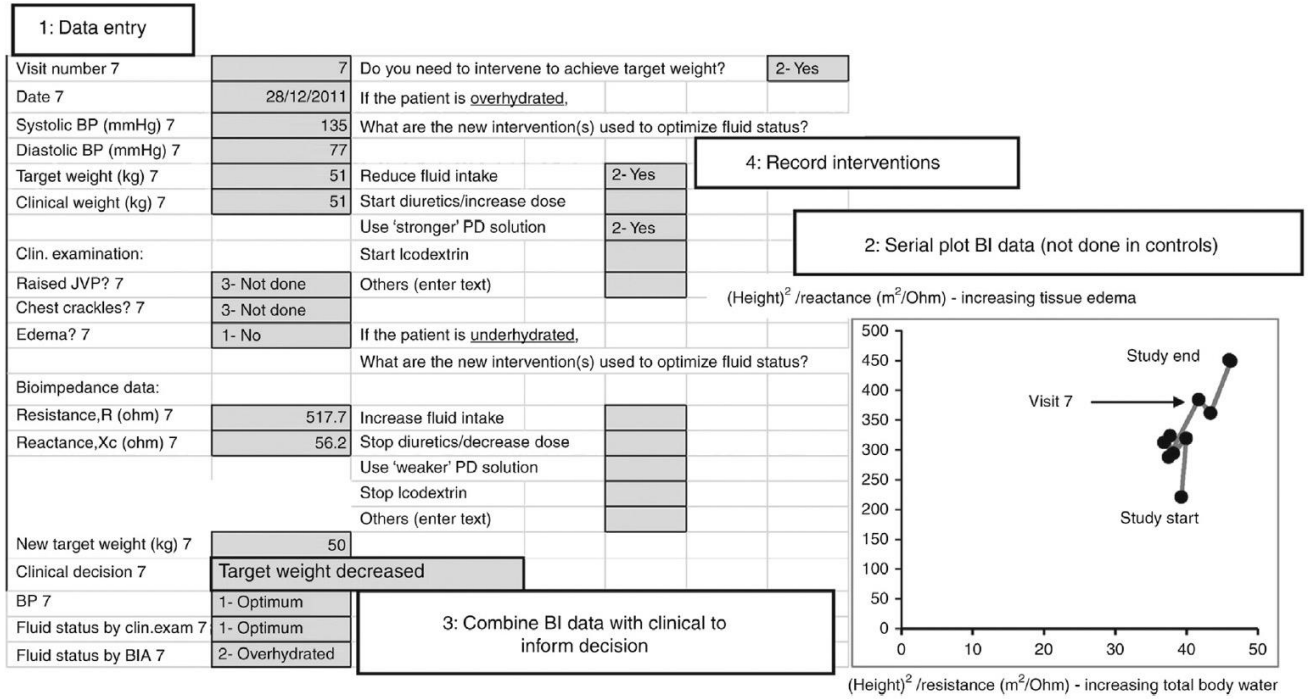


Figure 1 | The procedure for documenting clinical interventions is summarized. (Step 1) The clinical and bioimpedance (BI) data were entered onto an electronic clinical research record. For the intervention group, only BI data were automatically plotted (step 2) as the serial reciprocal height^2 (H^2) normalized data. In this format, increasing H^2/resistance implies increasing total body water and H^2/reactance reflects increasing extracellular fluid. (Step 3) This was then combined with clinical observations to inform the decision. In this example shown at assessment number 7, although the patient was clinically euvolemic, the BI indicated a progressive overhydration with lengthening and widening of the BI vector, and hence the target weight was reduced. Step 4 records the methods used to achieve this, in this case both advising reduced fluid intake and increased glucose prescription. This resulted in a temporary reduction in the phase angle, but this patient went on to become progressively overhydrated despite further reductions in target weight. This example shows that patients with unstable fluid status could have additional assessments (i.e., more than the five standard study visits; see also Supplementary Material online for further examples).

The results of a randomized control trial evaluatiog the value of bioimpedance vector plot in fluid management of PD patients

Table 2 | Longitudinal changes on body composition

	UK nonanuric						Shanghai nonanuric						Shanghai anuric					
	Control			BI intervention			Control			BI intervention			Control			BI intervention		
	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value
ECW (l)	19.5 ± 4.2	19.7 ± 4.6	0.70	18.2 ± 4.3	18.4 ± 4.0	0.57	16.0 ± 2.4	16.1 ± 2.6	0.84	17.2 ± 2.5	16.7 ± 3.2	0.25	17.7 ± 3.2	18.3 ± 4.6	0.342	16.3 ± 3.2	16.2 ± 2.6	0.787
TBW (l)	42.9 ± 8.6	42.8 ± 8.8	0.92	41.3 ± 8.4	40.4 ± 7.9	0.05	34.3 ± 6.6	34.2 ± 6.9	0.82	35.4 ± 5.2	34.7 ± 5.8	0.10	37.2 ± 6.0	35.5 ± 5.9	0.001	35.0 ± 6.5	34.0 ± 5.5	0.179
ECW/TBW	0.46 ± 0.06	0.46 ± 0.07	0.56	0.44 ± 0.08	0.46 ± 0.06	0.17	0.47 ± 0.06	0.47 ± 0.06	0.75	0.48 ± 0.08	0.48 ± 0.07	0.89	0.48 ± 0.06	0.51 ± 0.09	0.013	0.47 ± 0.06	0.48 ± 0.08	0.221
H^2/R (cm^2/Ω)	59.8 ± 14.0	59.9 ± 14.4	0.93	58.3 ± 14.5	56.9 ± 13.8	0.13	49.5 ± 17.4	48.9 ± 10	0.61	48.5 ± 10.4	49.3 ± 9.8	0.08	54.7 ± 10.5	50.4 ± 9.8	0.001	50.5 ± 12.3	48.5 ± 10.4	0.168
H^2/X (cm^2/Ω)	576 ± 171	595 ± 221	0.39	539 ± 175	543 ± 176	0.88	499 ± 127	498 ± 154	0.98	538 ± 146	529 ± 183	0.72	567 ± 147	621 ± 253	0.209	505 ± 139	511 ± 145	0.815
Phase angle (degrees)	6.14 ± 1.2	6.13 ± 1.55	0.91	6.59 ± 2.08	6.25 ± 1.35	0.25	6.14 ± 1.20	6.13 ± 1.55	0.82	5.50 ± 0.82	5.66 ± 1.49	0.42	5.72 ± 1.30	5.15 ± 1.72	0.03	5.90 ± 1.36	5.75 ± 1.68	0.50
Target weight (kg)	78.7 ± 19	78.3 ± 19	0.44	75.2 ± 15	73.6 ± 15	0.01	59.2 ± 9.0	58.7 ± 9.1	0.20	60.7 ± 8.6	60.3 ± 8.6	0.30	61.4 ± 10.2	60.8 ± 10.5	0.099	58.3 ± 9.8	58.1 ± 8.9	0.588
Clinical weight (kg)	79.3 ± 18	79.0 ± 19	0.72	75.8 ± 16	74.5 ± 15	0.07	59.2 ± 9.0	60 ±9.7	0.13	60.7 ± 8.6	60.6 ± 8.8	0.94	61.2 ± 10.4	60.9 ± 10.9	0.586	58.3 ± 9.8	57.9 ± 8.4	0.622

BI, bioimpedance; ECW, extracellular water; H^2/R, height^2/resistance, H^2/X, height^2/reactance; TBW, total body water. Phase angle is calculated as the arc tangent $((H^2/R)/(H^2/X))$ expressed in degrees.

The results of a randomized control trial evaluatiog the value of bioimpedance vector plot in fluid management of PD patients

Table 4 | Longitudinal changes in secondary outcomes and dialysis prescription

	UK nonanuric						Shanghai nonanuric						Shanghai anuric					
	Control			BI intervention			Control			BI intervention			Control			BI intervention		
	Baseline	12 Months	*P*	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value	Baseline	12 Months	*P*-value
Systolic BP (mm Hg)	144 ± 25	140 ± 20	0.209	137 ± 20	136 ± 20	0.845	133 ± 16.2	135 ± 18.4	0.375	131 ± 15	130 ± 21	0.637	128 ± 24	123 ± 27	0.638	130 ± 22	128 ± 26	0.776
Diastolic BP (mm Hg)	81.2 ± 13	79.1 ± 10	0.235	79.7 ± 11	79.2 ± 11	0.815	85.5 ± 8	86.1 ± 13	0.991	83.3 ± 11	81.9 ± 11	0.410	79.7 ± 9	76.2 ± 16.2	0.246	79.8 ± 13.1	81.6 ± 14.9	0.613
Input volume (l)	8.8 ± 2.5	9.4 ± 3	0.032	8.7 ± 2.7	9.0 ± 3	0.079	6.1 ± 1.8	6.5 ± 1.8	0.025	6.6 ± 1.5	6.9 ± 1.4	0.025	8.3 ± 1.3	8.6 ± 1.4	0.083	7.8 ± 1.2	8.0 ± 1.2	0.157
Total glucose (g)	121.7 ± 5	126.7 ± 6	0.395	119.1 ± 51	126.8 ± 57	0.067	104.2 ± 35	120.0 ± 39	0.001	116.0 ± 31	130.0 ± 36	0.003	181.2 ± 41	186.7 ± 51	0.398	167.5 ± 39	176.3 ± 46	0.037
Average (glucose; g/l)	1.36 ± 0.28	1.3 ± 0.4	0.257	1.31 ± 0.37	1.34 ± 0.39	0.417	1.71 ± 0.32	1.86 ± 0.34	0.009	1.75 ± 0.27	1.87 ± 0.34	0.006	2.16 ± 0.31	2.15 ± 0.39	0.888	2.13 ± 0.33	2.19 ± 0.39	0.342
Daily UF	326 ± 629	446 ± 435	0.113	339 ± 539	439 ± 418	0.203	160 ± 437	352 ± 487	0.003	166 ± 514	316 ± 568	0.012	876.4 ± 296	792 ± 402	0.384	833 ± 327	831 ± 363	0.819
Urine volume (ml)	1,298 ± 746	1,007 ± 599	0.003	1,165 ± 661	1,170 ± 896	0.957	1,084 ± 621	746 ± 559	0.000	1,005 ± 571	723 ± 654	0.000	NC	NC		NC	NC	
Renal Ccr (L/week/1.73 m^2)	94.6 ± 63	78.1 ± 57	0.020	93.1 ± 66.1	72.3 ± 62.6	0.001	40.1 ± 35.3	33.9 ± 38.7	0.012	41.7 ± 33.1	27.2 ± 26.5	0.000	NC	NC		NC	NC	
Renal Kt/V	1.3 ± 0.8	1.1 ± 0.7	0.023	1.2 ± 0.8	1.0 ± 0.8	0.006	0.8 ± 0.6	0.6 ± 0.6	0.007	0.7 ± 0.5	0.5 ± 0.5	0.000	NC	NC		NC	NC	
Albumin (g/l)	33.5 ± 4.0	32.9 ± 3.7	0.301	33.2 ± 4.7	33.2 ± 5.0	1.00	38.0 ± 3.4	38.2 ± 4.6	0.466	37.8 ± 2.8	38.4 ± 3.3	0.307	38.9 ± 3.3	38.2 ± 4.3	0.548	39.2 ± 3.0	38.0 ± 3.5	0.130
UF capacity	274 ± 216	244 ± 220	0.572	226 ± 266	279 ± 294	0.357	253 ± 111	291 ± 138	0.147	221 ± 174	266 ± 130	0.299	274 ± 139	252 ± 153	0.701	241 ± 196	267 ± 129	0.247
Solute transport	0.66 ± 0.11	0.68 ± 0.10	0.156	0.70 ± 0.14	0.73 ± 0.11	0.175	0.58 ± 0.11	0.60 ± 0.12	0.231	0.60 ± 0.10	0.62 ± 0.10	0.255	0.64 ± 0.11	0.67 ± 0.11	0.032	0.62 ± 0.11	0.67 ± 0.11	0.001

BI, bioimpedance; BP, blood pressure; Ccr, creatinine clearance; Kt/V, urea clearance (weekly); NC, not collected; UF, ultrafiltration from peritoneal equilibration test.

In the UK-nonanuric BI intervention group, the fall in TBW was because of setting of a lower target weight but no change in ECW/TBW ration or improvement in blood pressure.

Thus, routine use of of longitudinal BI vector plot to improve clinical management of fluid fluid status is not supported by this study.

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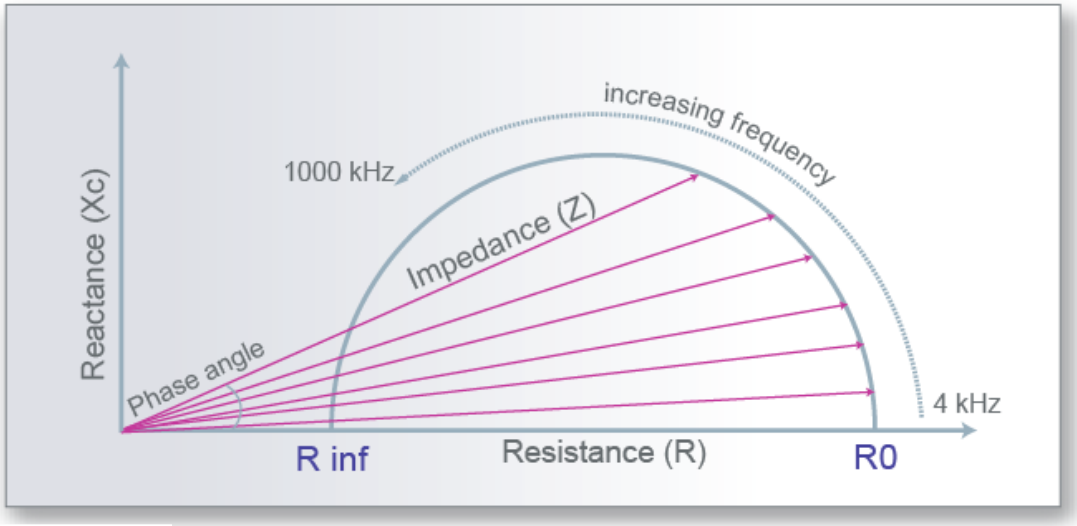
BIS (bioimpedance spectroscopy)

- In contrast to MF-BIA, BIS uses mathematical modeling to generate relationship between R and fluid compartements to predict R_0 and R_{inf}.
- BIS have shown to be accurate with minimal bias in non-physiological conditions.



R inf

Impedance at infinite KHz (Impedance TBW)

BIS

Scans from low (4 kHz) to high (1000 kHz) frequencies 400-500 discrete data points

R 0

Impedance at 0 kHz (Impedance ECF)

S-BIA (segmental BIA)

Segmental-BIA is performed by placing two additional electrode on wrist and foot on the opposite side, shoulder (acromion), and upper iliac spine.

Three aspects of S-BIA:

- Changes of the impedance are closely related to changes of the FFM, muscle mass or body cell mass (BCM)) of the limbs.
- It may detects the changes of trunk FFM that are not adequately described by whole body impedance measurements.
- Segmental BIA must be used to determine fluid shifts and fluid distribution in some diseases (ascites, renal failure, surgery), and may be helpful in providing information on fluid accumulation in the pulmonary or abdominal region of the trunk.

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DIALYSIS – TRANSPLANTATION

Estimation of body fluid changes during peritoneal dialysis by segmental bioimpedance analysis

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- Paticipants were 14 CAPD patients during standard exchange with fluids of known conductivity.
- Bioimpedance was continuously measured in the arm, trunk, and leg and from wrist to ankle.
- Volume changes were calculated using both segmental BIA (SBIA) and wrist-to-ankle BIA (WBIA) and were compared with volume changes measured gravimetrically.

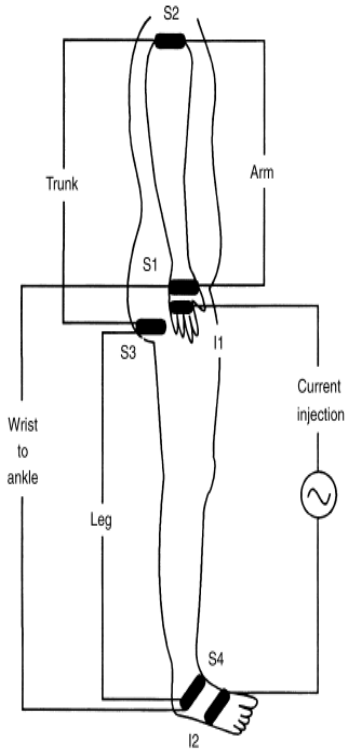


Table 3. Extracellular volume changes by WBIA and SBIA (N = 22)

Variable	Gender	WBIA	SBIA	Unit
ΔECV_D	m	0.29 ± 0.55	2.06 ± 0.51	L
	f	0.32 ± 0.36	2.11 ± 0.56	L
	m and f	0.30 ± 0.5	2.07 ± 0.51	L
$\Delta ECV_D/V_D$	m	12.7 ± 27.1	97 ± 12.9	%
	f	12 ± 13.5	89.2 ± 16.5	%
	m and f	12.5 ± 24.3	95.2 ± 13.8[a]	%
ΔECV_F	m	0.21 ± 0.48	1.94 ± 0.49	L
	f	0.03 ± 0.28	1.87 ± 0.27	L
	m and f	0.17 ± 0.45	1.93 ± 0.44	L
$\Delta ECV_F/V_F$	m	10.9 ± 22.6	91.5 ± 21.2	%
	f	1.8 ± 14.2	89.8 ± 14.8	%
	m and f	8.8 ± 21.1	91.1 ± 19.6[a]	%

Abbreviations are: WBIA, wrist-to-ankle analysis; SBIA, sum of segments analysis; N, number of studies; ΔECV, changes in ECV during filling; ΔECV/V, percentage of volume recovered by bioimpedence analysis (BIA); index F, related to filling; index D, related to draining.
[a] P = NS, one-sample sign test, H_0 = 100

- When 2.19 ± 0.48 L were removed from the peritoneal cavity during draining, 95.2 ± 3.8% of this volume was detected by SBIA compared with 12.5 ± 24.3% detected by WBIA.

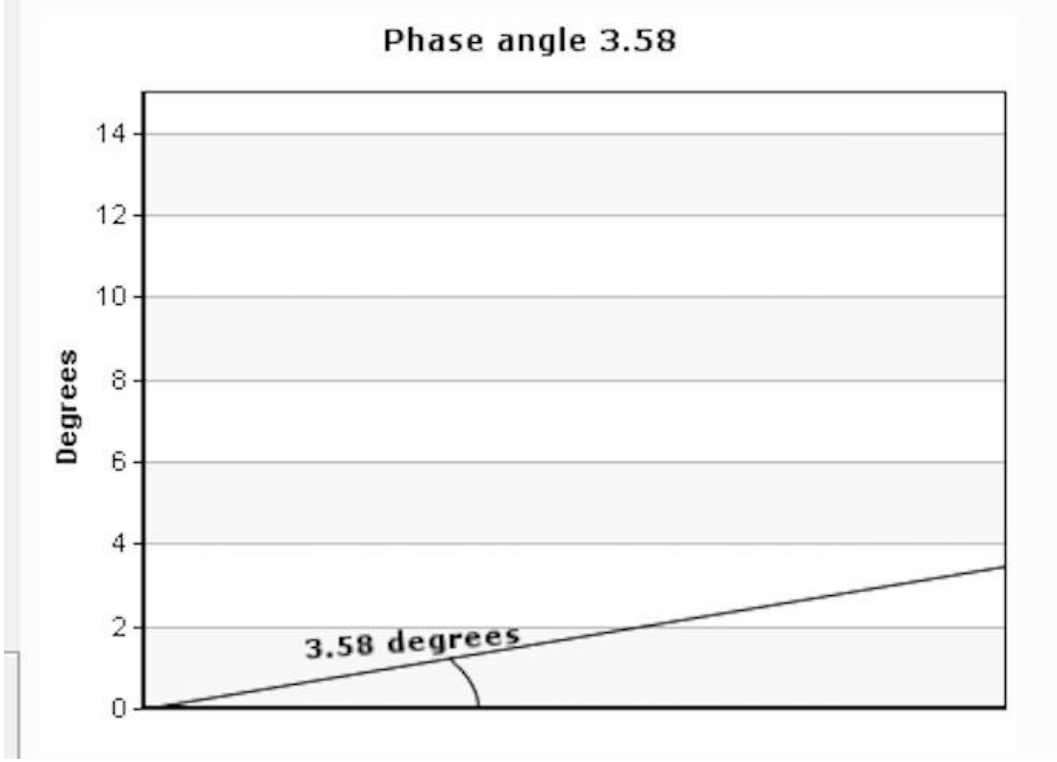
- When 2.11 ± 0.20 L of fresh dialysate was infused into the peritoneal cavity, 91.1 ± 19.6% of this volume was detected by SFBIA compared with only 8.86 ± 21.1% detected by WBIA.

Changes in extracellular fluid in trunk estimated by SBIA is relatively accurate.

results

An example of the body composition

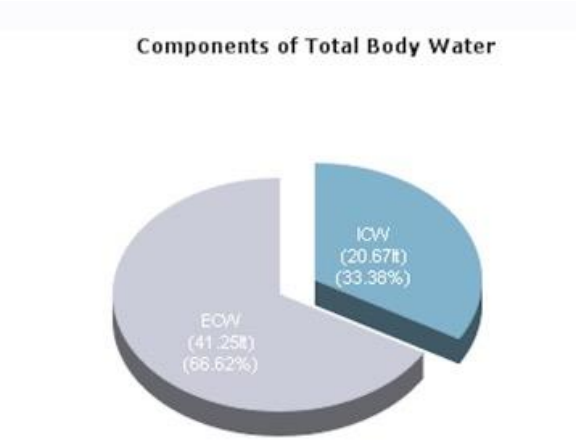
The phase angle: the arctangent of Xc/R

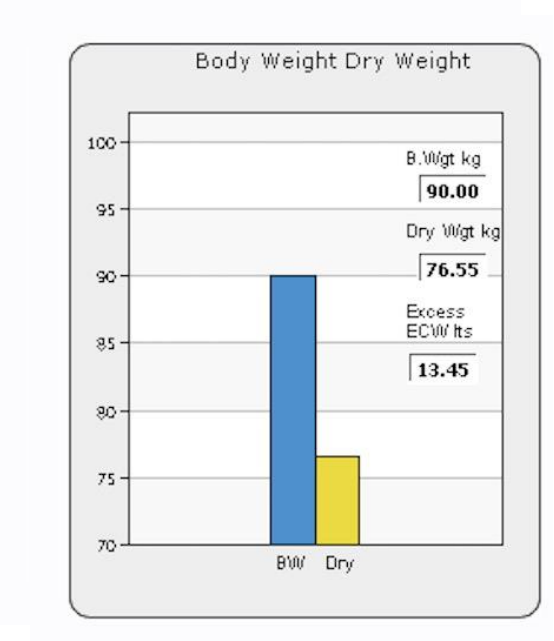


The reasons for low phase angle:

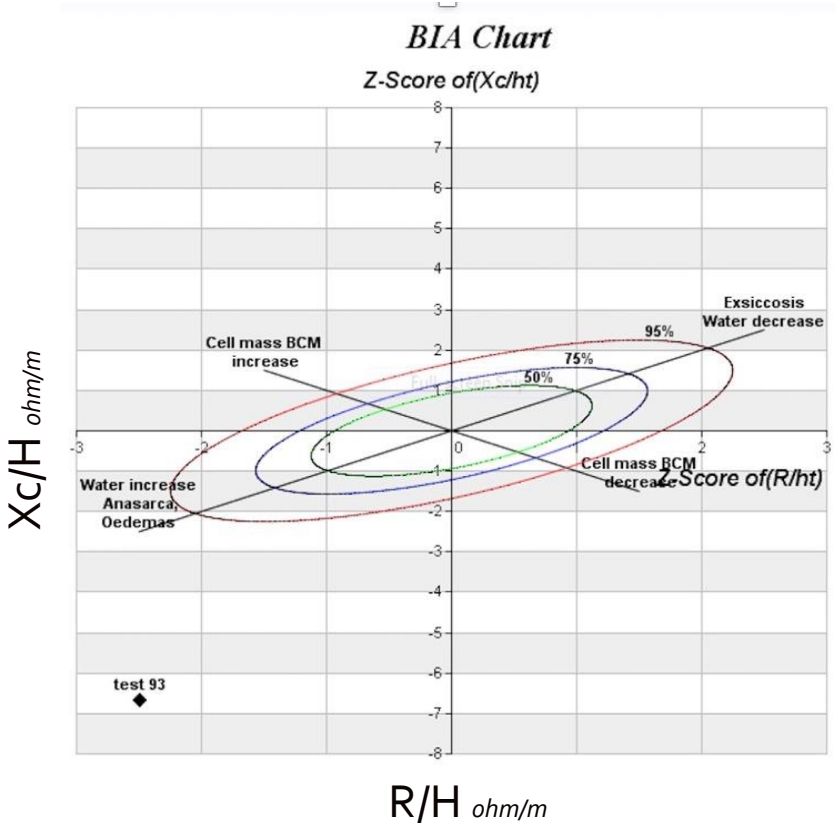
1. Low cell mass
2. Fluid overload

Test number:93





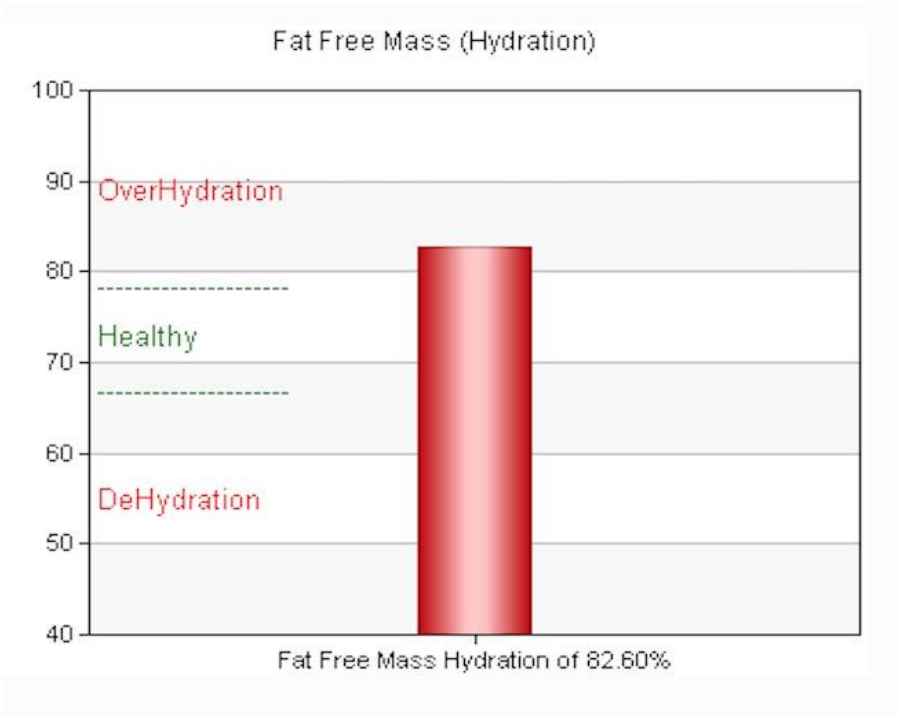
The proportional of intracellular and extracellular fluids and the suggested dry weight and excess water by BioScan analyzer



with data expected to fall within 75% tolerance ellipse.

The patient is overhydrated because his location is below the major axis of 75% tolerance ellipse.

Test number:93


Fat Free Mass (Hydration)
100
90
80
70
60
50
40
OverHydration
Healthy
DeHydration
Fat Free Mass Hydration of 82.60%

Summary:

- Clinical findings are not accurate and sensitive for estimation of volume status in patients with ESRD.

- Bio-impedance is a safe, simple and rapid method for estimation of volume status in end stage kidney disease. However, we need standardization of the current techniques and reference equations for special kidney related population (CKD, HD,PD).

- Segmental BIA may be beneficial in determination of trunk and outflow failure. However, this method has not yet been sufficiently standardized to be used in PD patients.

- Well designed future studies with a long follow up period should be performed to better describe the effect of BIA based strategies on survival in PD patients.