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Reversibility of artifacts of fluid volume measurements by bioimpedance caused by position changes during dialysis

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ABSTRACT:

The effect of temporary position changes, sitting up from supine, on extracellular (ECW) and intracellular (ICW) resistances and fluid volumes calculated from whole body bioimpedance using a Xitron 4200 impedancemeter was investigated on 8 patients during dialysis for a total of 11 tests. It was found that ECW resistance decreased instantaneously by an average of 2.3% when the patient sits up, due to plasma and interstitial fluid shift into the legs which decreases leg resistance, the major contributor to total resistance. This drop in resistance is incorrectly interpreted by the device as an increase in ECW volume which averages 235 ml. But this effect is completely reversible and both ECW resistance and fluid volume rapidly resume their normal course when the patient returns to his initial position. No significant variation in ICW resistance was observed in any of the patients at the position change. We conclude that segmental impedance, which has been proposed to minimize this artifact, is not advisable in dialysis monitoring and that it is simpler to ignore or switch off measurements during the position change so that later data are not affected by it.

INTRODUCTION

Extracellular (ECW) fluid volume monitoring during dialysis has been proposed by various investigators (1-4) to monitor the state of hydration of patients and trans- cellular fluid transfers. Presently the most accurate method combines multifrequency impedance (or Bio Impedance Spectroscopy, BIS) measurements from 5 to 500 kHz with Hanai's (5) theory for the conductivity of a suspension, which accounts for the presence of non conducting elements in tissues such as, fat, bones and, at low frequencies, cells (6-8). However the technique of measuring fluid volume from whole body impedance in which voltage electrodes are placed on the ankle and wrist is subject to artifacts when the patient changes position, which is generally unavoidable during a 4-hour treatment. The effect of posture on ECW volume determination from impedance has been recognized by Thomas et al (9) and Zhu et al (10-12). The physical explanation for this artifact is that the limbs contribute more than the trunk to the body impedance, due to their smaller cross section. Therefore, when a patient sits up from a supine position, interstitial fluid and blood are shifted from the trunk into the legs by gravity and the ECW resistance of the leg, which is great, decreases more (in ohms) than the trunk resistance eventually increases. Thus, the whole body ECW resistance, which is equal to the sum of three resistances in series, arm, trunk and leg, will decrease. This resistance decrease will be interpreted by the BIS method as a volume increase, since volume and resistance vary in opposite directions, no matter which electrical model is used for the tissues. Thus it is clear that the whole body impedance method of ECW volume measurement is subject to artifacts when a patient changes position, because of internal ECW shift between the trunk and the limbs.

Both authors (9,10) suggested replacing whole body impedance with the sum of segmental impedances of leg, trunk and arm as a method to minimize such artifacts. However, especially in the case of dialysis which requires continuous impedance measurements, the segmental method is cumbersome to use as it requires two additional electrodes to be pasted on the shoulder and the hip and shifting the measurements between each of three pairs of voltage electrodes. Therefore, since patient position changes during dialysis are generally temporary, it is legitimate to investigate the reversibility of fluid shifts between the trunk and the legs in order to see whether the time course of the ECW resistance is affected when the patient resumes his initial position.

MATERIALS AND METHODS

Patients

Data were collected on 8 patients (5 male, 3 female) who had given informed consent, for a total of 11 runs. Characteristics of patients and their positions are listed in Table I. Each patient is identified by a letter and the number indicates the test number. The tests labeled run 9 (P1a) and 10 (P1b) were in fact carried out during the same dialysis run, but corresponded to two successive changes in position. In 6 runs (N° 3, 4, 5, 6, 8, 9) the patient was either supine or semi-supine and returned to the same position after sitting up in bed. Only in runs 7 and 10, had the patient, who had been supine, returned to a semi-supine position because he felt better. In the remaining runs (1, 2, 11), the patient was reclining in an armchair with his legs up and sat upright temporarily with his legs down. The timing and the details of position changes were recorded. The letter A in the position change column of Table I indicates supine, B: semi-supine (reclining in bed), while C indicates sitting in bed and D sitting in an armchair with legs hanging down. Bioimpedance measurements were taken with a XITRON 4200 which operates automatically at multiple frequencies between 5 and 1000 kHz. This device calculates the ECW resistance Re by extrapolation of impedance to zero frequency. Self adhesive silver coated electrodes 7.5 cm x 1.9 cm were placed in pairs on the ankle and the wrist of the same side. The two current electrodes were placed distally about 5 cm from the proximal voltage ones. The patients were weighed before and after the dialysis treatment and the ultrafiltered volume was recorded as a function of time.

Calculation of fluid volume by impedance

As indicated by De Lorenzo et al (6), the Xitron calculates the ECW volume VECW using

$$V_{ECW} = \left(\frac{H^2 W^{1/2}}{R}\right)^{2/3} \quad (1)$$

where W is the body weight in kg, H the height in m and kECW = 0.306 for men and 0.316 for women, according to Van Loan et al (13). We have compared the ECW volumes given by the Xitron post dialysis with values calculated using the anatomical correlation of Watson et al (14). Male:

$$VTBW = 2.447 – 0.09156\ age + 10.74\ H + 0.3362\ W \quad (2)$$

where H is in m, W in Kg, age in years Female:

$$VTBW = -2.097 + 10.69\ H + 0.2466\ W \quad (3)$$

The estimation of ECW volume Ve at the time of position change using equations (2) and (3) and Ve = 0.405 VTBW for men and 0.435 VTBW for women according to (4, 5) is listed in the last column of Table I. The device also computes the ICW resistance Ri from Re and extrapolation at infinite frequencies using a standard procedure (5, 6).

RESULTS AND DISCUSSION

ECW resistance and volume tracings during a position change

The recordings of runs 4, 9 and 1 are displayed in Figures 1, 2 and 3 respectively. The patient of Figure 1 laid supine, then sat up for 14 min and returned to a supine position (Tab. II). When she sat up, her ECW resistance dropped instantaneously from 725 Ω to 705 and continued to decay to 695 Ω. When she returned to a supine position, her resistance increased suddenly by 30Ω to 725 Ω and then rose slowly afterwards due to ultrafiltration. This was one of the 3 cases in which the resistance continued to decay when the patient was sitting. Perhaps she adjusted progressively to an upright position and her legs continued to fill up during the sitting period. The patient represented in Figure 2 was laying supine in bed when she sat up for 31 min to have a snack. As seen in the figure and in TableII, her resistance dropped by 24 Ω from 748Ω to 724 Ω, then rose with time at the same rate as before the position change and jumped from 746 to 761 Ω (+ 25 Ω) when she returned to a reclining position. We have also represented in Figure 2 the variation of ECW volume which is the mirror image of the resistance variation, as could be expected from equation (1). The volume variations, before and after the position change, are well correlated by the same straight line. The case of run 1 depicted in Figure 3 is interesting because this patient, who was reclining in an arm chair, sat twice within a short period with his legs hanging down. Figure 3 shows the reproducibility of tracings when the patient repeats the same movement. His resistance dropped by 22 Ω from 518 Ω to 496 Ω when he sat up and increased by 18 Ω to 532 Ω when he laid down again. Here again, ECW volume tracings before and after sitting are well correlated by the same straight line. Table II lists the ECW resistance data, pre and post resistances, pre and post resistance changes DRe in Ω and in % for all patients. It can be seen that the mean pre and post resistance changes are very close (15 and 16 Ω respectively).

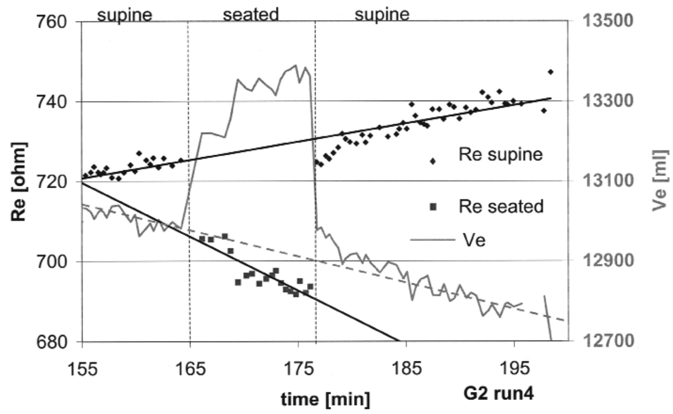


Fig. 1 - *Variation of ECW resistance of patient G2 (run 4) who sat up in bed and returned to supine position. Notations relative to Table II are also indicated.*

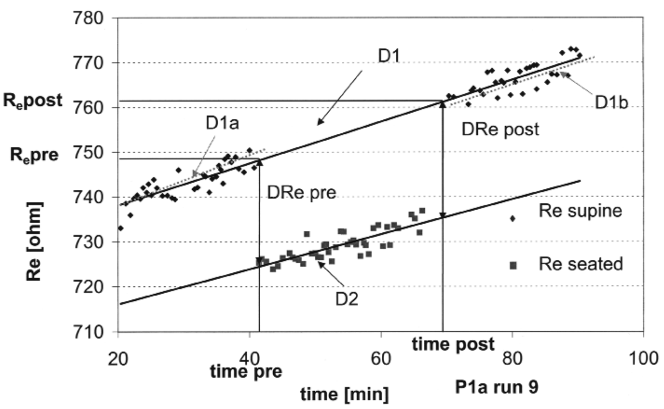
TABLE I - CHARACTERISTICS OF PATIENTS AND THEIR POSITIONS DURING DIALYSIS HAVING A SNACK WHILE SITTING IS INDICATED

Run	Patient	Sex	Age (yr)	Weight (kg)	Height (cm)	Q_{UF} (ml/h)	Position change	Time pre (min)	Time post (min)	Duration of position change (min)	V_e Watson (liter)
1	B1	M	47	77.2	173	800	BDB	98	128	30	16.85
2	B2	M	47	74	173	1000	BDB	84	92	8	16.86
3	G1	F	56	62.5	157	700	ACA (snack)	41	48	7	13.15
4	G2	F	56	68	157	780	ACA	164	178	14	13.4
5	I1	M	61	48	153	900	BCB	127	137	10	11.51
6	J1	M	73	63.4	160	850	BCB	114	125	11	13.41
7	N1	M	66	65	173	400	ADB	130	145	15	14.73
8	O1	F	62	67.2	175	550	BCB (snack)	47	80	33	14.09
9	P1a	F	64	55.2	175	150	ACA (snack)	40	71	31	10.06
10	P1b	F	64	55.2	175	150	ACB	133	145	12	12.06
11	Q1	M	69	77.6	169	650	ADA (snack)	65	90	25	16.02
Mean			60.5	65.09	167	630		94.82	112.6	17.82	13.83
Stand. dev.			8.31	9.41	8.65	289		43.53	39.07	9.91	2.18

A: supine; B: semi-supine (reclining in bed); C: sitting in bed; D: sitting in un armchair with legs hanging down
1,2 indicate test number for each patient. 1a, 1b refer to two successive recordings in the same test.

Continuity of resistance tracings after a position change

To further verify the continuity of resistance tracings before and after a temporary position change, which would imply a reversibility of the fluid distribution, we have calculated the slopes of regression lines D_{1a} and D_{1b} (Fig. 2) corresponding to ECW resistances data during periods of 20 min before and after position change. We have also calculated the slope and correlation coefficient of a single regression line D_1 corresponding to the pre and post resistance data as well as of the line D_2 corresponding to the sitting position. Table II lists these regression slopes and correlation coefficients for all patients. It can be seen that slopes of D_{1a} and D_{1b} are not significantly different in the same patient (paired Student's test: $p = 0.95$), except for runs 7 and 10 which are those in which the patient did not return to the same supine position but to a semi-supine one. Similarly the coefficients R^2 of D_1 lines are very high, except for runs 7 and 10 and correspond to a correlation significant to $p<0.001$. This confirms that the resistance has resumed its normal course just as soon as the patient has resumed his initial position. The slopes and regression coefficients of lines D_2 of resistance data during the seated period are also listed in Table II. Only in runs 1, 3, 8, 9, 10 and 11 do the resistance tracings during the position change remain approximately parallel to those before and after the change, while they take a decreasing course in runs 2, 3 and 6. In run 5, the slope of D_2 is much higher than that of D_1, while in run 6, the resistance remains nearly constant during sitting.



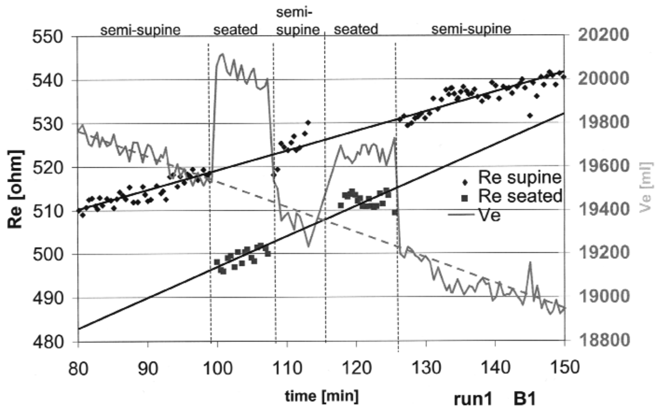


Fig. 2 - *Variation of ECW resistance and volume of patient P1a (run 9) who sat up in bed and returned to supine position.*

Fig. 3 - *Variation of ECW resistance and volume of patient B1 (run 1) who sat up twice in bed during a short period before returning to semi-supine position.*

TABLE II - EWC RESISTANCES AND RESISTANCE CHANGES BEFORE, DURING AND AFTER POSITION CHANGE. WITH THE NUMBER OF POINTS USED FOR THE REGRESSIONS, ALL R^2 COEFFICIENTS ARE ASSOCIATED WITH P < 0.001

Run	Patient	R_e (ohm)		DR_e (ohm)		% R_e change		Regression slope (Ω/min) D1a	D1b	D1	D2	R^2 D1	D2
		pre	post	pre	post	pre	post	pre	post	pre+post	position change	pre+post	position change
1	B1	518	532	22	18	4.25%	3.38%	0.45	0.45	0.45	0.7	0.97	0.91
2	B2	536	544	9	10	1.68%	1.84%	0.2	0.19	0.19	-0.35	0.78	0.24
3	G1	666	674	6	6	0.90%	0.89%	0.51	0.51	0.51	0.48	0.98	0.6
4	G2	725	725	20	30	2.76%	4.14%	0.56	0.46	0.46	-1.32	0.92	0.74
5	I1	684	693	23	23	3.36%	3.32%	1.04	1.33	1.31	5.05	0.97	0.96
6	J1	528	532	9	12	1.70%	2.26%	0.65	0.64	0.64	-0.04	0.93	0
7	N1	817	812	11	18	1.35%	2.22%	0.26	0.17	0.18	-2.12	0.65	0.73
8	O1	613	630	15	12	2.45%	1.90%	0.5	0.48	0.48	0.58	0.97	0.38
9	P1a	748	761	24	25	3.21%	3.29%	0.48	0.46	0.46	0.39	0.97	0.68
10	P1b	786	787	20	20	2.54%	2.54%	0.21	0.19	0.19	0.55	0.47	0.11
11	Q1	748	761	8	7	1.07%	0.92%	0.29	0.29	0.46	0.39	0.91	0.9
	Mean	670	677	15.2	16.5	2.30%	2.43%	0.47	0.47	0.48	0.39	0.87	0.57
	Stand. Dev	107	104	6.79	7.72	1.06%	1.04%	0.24	0.32	0.31	1.78	0.17	0.34

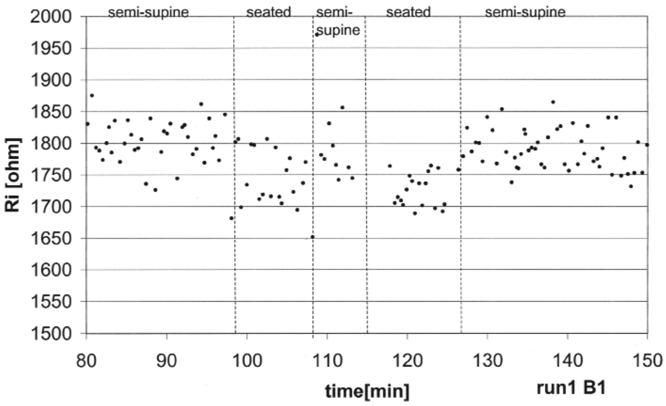


Fig. 4 - *Variation of ICW resistance of patient B1 (run1) during the same time period as in Figure 3.*

The instantaneous ECW volume changes DV_e at each position change, calculated from equation (1), are listed in Table III (columns 3 and 4). It can be seen that the mean values of these two volume changes are very close. We have also compared variations of ECW volume ($V_{e1} - V_{e2}$) calculated using Equation (1) before and after the sitting period with the water loss by ultrafiltration DV_{TBW}. The mean ECW difference is 19% smaller at 140 ml than the water loss, which can be expected due to ICW contribution. In the last three columns of Table III we have compared the ultrafiltration rate with the ECW volume depletion rate Q_e in ml/min which the slope of the regression with time of V_e given by impedance before and after the position change, eliminating in this process the effect of sitting period duration. Here again it is found that the depletion rate is 24% lower on average than the ultrafiltration rate. The difference with the percentage given for the volumes is due to the fact that this calculation was averaged along a one hour period while the volumes were compared at the instants of position change.

No significant variation in ICW resistance was observed during the position change in any of the patients, even in runs 1 and 9 which showed the largest changes in R_e. Figure 4 illustrates the case of run 1. This can be expected since ICW fluid, except red cells, is not as free to move as blood or interstitial fluid under the effect of gravity.

CONCLUSION

Our data show that, if there is indeed a sudden rise of 100-300 ml in ECW volume calculated by whole body impedance and corresponding to a decrease of leg resistance when a patient sits up temporarily in bed or an armchair during dialysis, this volume increase is, in most cases, reversible, and both resistance and volume tracings resume their normal course when the patient returns to his initial position. Thus, we do not think that it is advisable to use segmental impedance with 6 electrodes, as this technique is cumbersome, since it requires placing additional electrodes on the patient's shoulder and hip. In addition it reduces the number of available data on whole body resistance as measurements must be shifted between each of three pairs of voltage electrodes. Even more important is the absence of a validated method for computing segmental volume changes, while the whole body method has been validated against isotopic dilution methods. It is simpler to disregard the part of the signal during the position change or to replace it by a straight line connecting tracings before and after position changes.

TABLE III - ECW VOLUME VARIATIONS AND COMPARISON OF ECW DEPLETION RATE WITH ULTRAFILTRATION BEFORE AND AFTER POSITION CHANGE

Run	Patient	DV_{e1} pre (ml)	DV_{e2} post (ml)	V_{e1} - V_{e2} (ml)	DV_{TBW} (ml)	Q_{UF} (ml/min)	Qe (ml/min)
1	B1	568	441	375	400	13.33	12.25
2	B2	212	230	195	133	16.67	6.11
3	G1	81	80	112	82	11.67	7.77
4	G2	241	365	12	182	13.00	6.17
5	I1	267	261	113	150	15.00	16.55
6	J1	185	245	94	156	14.17	18.5
7	N1	123	204	-48	100	6.67	2.56
8	O1	280	213	329	303	9.17	5.74
8	P1a	300	303	162	78	2.50	1.98
10	P1b	228	228	14	30	2.50	5.87
11	Q1	106	90	186	271	10.83	4.14
Mean		235.59	241.74	140.23	171.24	10.50	7.97
Stand. Dev.		132.02	105.25	129.61	111.16	4.82	5.47

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List of symbols

DVe	ECW volume change
ECW, ICW	Extracellular water, intracellular water
H	Patient height
kECW	Constant in equation (1)
Qe	ECW depletion rate
QUF	Ultrafiltration rate
Re, Ri	ECW, ICW resistance
Ve	ECW volume

VTBW Total body water volume

W Patient weight

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