MONITORING OF BIOIMPEDANCE DATA DURING EXERCISE IN CYCLISTS

Marie-Valérie Moreno [1], Gilbert Moreno [2], Florent Hubert [1]

(1) : BioparHom, La Base, Technolac, 73310 Le Bourget du Lac, France
06.18.20.01.40
(marie-valerie.moreno,florent.hubert)@bioparhom.com

(2) : TAC, 169 chemin le verger, 69380 Chasselay, France
06.88.49.68.28
gilbert.moreno@wanadoo.fr

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Abstract: the objective of this study was to observe if it's possible to measure reliable bioimpedance data with our prototype during exercise, despite the movement of the body in this sport. In a second time, we wanted to investigate the reliability of fat mass measurement after exercise. Finally, we wanted to study if it is possible to observe variations of metabolism by bioimpedance during effort.

12 cyclists of the cycling club of Tour de Salvagny (TAC) participated to the study. We used two devices, a foot-to-foot impedancemeter, Tanita© Innerscan® for fat mass, and our prototype of multifrequency impedancemeter, BioparHom© Z-Metrix®, to measure the resistance (R), the reactance (X), the phase,angle and the resistances of extracellular (Re) and total body (Rinf) compartment, obtained by our model derived from Cole-Cole model. A measure was made each 1min30s during exercise. We asked cyclists to stabilise their effort at 75% of their maximal heart rate reserve during 30 minutes and then attempt a maximal effort once or twice. We showed that measurement of fat mass after exercise is not relevant, with a foot-to-foot or wrist-ankle impedancemeter using these equations in standing position, which were originally developed for standing position. We saw that during a constant effort, the signal was stable. We observed the variations of metabolism of cells'membranes thanks to phase angle parameter during maximal effort. We noted a difference in metabolic behaviour between hard training and low training subjects.

To conclude, our prototype can be reliable for monitoring bioimpedance data despite the movements during exercise but we have to modify our equations to obtain a reliable fat mass after exercise.

Key words: bioimpedance, monitoring, resistance, reactance, phase angle, body composition.

1- Introduction

Body composition analysis by bioimpedance is a convenient tool as it is non invasive and can be repeated frequently. It can be used during exercise with an adapted device. In sport, bioimpedance is seen as a no reliable technique, that's why we wanted to investigate two devices: a foot-to-foot (FFI) and a wrist-ankle (WA) impedancemeters.

The aim of this study was, firstly, to observe if it's possible to measure reliable bioimpedance data with our prototype of Z-Metrix® during exercise, despite the movement of legs in cycling. In a second time, we want to see the effect of a loss of water on the results of body Fat Mass (FM). Finally, we wanted to investigate if we could observe changes in fluid or bioimpedance data during exercise.

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2- Materials and methods

12 cyclists of the cycling club of Tour de Salvagny (TAC) participated to the study. Their physical characteristics are summarised in Table 1.

Cyclists Data	Mean	sd
Age (years)	45.0	8.8
Weight (kg)	73.4	5.2
Height (cm)	177.6	7.6

Table 1: principal physical characteristics of our 12 cyclists (men)

We did measurements before and after exercise in standing position and on the bicycle with our WA device, but it was impossible to do the same protocol with the FFI because of its design.

We asked cyclists to do an effort during 30 minutes and to try to stabilise their effort at 75% of their heart rate reserve, obtained by the difference between maximal heart rate and heart rate at rest. Then they attempt a maximal effort once or twice. A whole body measurement with Z-Metrix® was made each 1min30s during exercise. The aim was to be sure that athletes do not loose FM during this protocol.

Two impedancemeters were used in this study, a multifrequency BioparHom Z-Metrix® (WA) measuring whole body with two electrodes on right hand and two on right foot as described in (Jaffrin et al., 2002), and a Tanita InerScan® (FFI) with 4 reusable electrodes under heels and toes which give essentially Fat Mass (FM). The first device uses patented equations to calculate: the resistance of extracellular compartment (Re), resistance of total body compartment (Rinf) using a new model derived from Cole-Cole model (Cole and Cole, 1941), FM, Lean Body Mass (LBM), Bone Mineral Content (BMC), total body water (Vt), extracellular water volume (Ve), intracellular water volume (Vi) and various estimation of sodium and potassium extra or intracellular concentration, (ECENa, ICK, ECK) plasmatic volume (Vp), red cell volume (Vred_cell), blood volume (Vblood), hydration rate of FFM (Vt/FFM), hydration rate of body (Vt/W). The second device gives FM in percentage. FFM is calculated as the difference between Weight and FM. It requires entering manually in the software of both devices the subject height, age and sex, while his weight is measured by the FFI to within 0.1 kg and manually entered for the WA.

In addition, we have used Kotler's equations (Kotler et al., 1996) to obtain total body potassium TBK (in mmol) estimated from the reactance X and resistance R at 50 kHz by

$$TBK_{♂} = 44.89\ H^{1.6} / Xcp^{-0.5} + 18.52\ W - 386.66 \quad (1a)$$

$$TBK_{♀} = 1.248\ H^{2.07} / Xcp^{-0.36} + 5.79\ W - 230.51 \quad (1b)$$

where Xcp in ohm is the equivalent reactance given by

$$Xcp = X + R^2 / X \quad (2)$$

Wang's muscle mass in kg was calculated using (Wang et al., 2003)

$$Muscle\ Mass\ Wang = 0.0093\ TBK + 0.024\ A - 3.21 \quad (3)$$

Body cell Mass in kg was calculated using Leweling's equations (Leweling, 1995)

$$BCMl = FFM - 0.29 Ln(Phase\ Angle°) \quad (4)$$

Where Phase Angle in degree is calculated by

$$Phase\ Angle = Arctan\ (X/R) \quad (5)$$

We used paired Student t-tests as statistical method.

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3- Results

3.1 – Is there a difference between bioimpedance data in standing position and on bicycle position?

Table 2 shows some parameters measured by Z-Metrix®, firstly in standing position and secondly on bicycle. We can observe mean and standard deviation of the parameters, compared with paired Student t-test. We see that there is a significantly difference between Vt, Ve, Vi and BMC obtained in standing position and on bicycle if we express them in liter. That confirms the study of Fenech (Fenech et al., 2002) who supposed that current lines change during modifications of position. But, if we express Ve and Vi in percentage of Vt, and BMC in percentage of weight, the difference between the two position is not significant. We can suppose that the variations of one balance the other. We can think that this is the same for Ve/Vi, Ve/Vt and Re/Rinf. However, this is not the case for LBM and Muscle Mass. Although there is a non-significant difference for these parameters (X, Phase Angle, FFM and BCMl/H²), all the others data are significantly different, measured in standing position or on bicycle (R, Re, Rinf, TBK, Vp, Vred-cell, Vblood, ECENa, ECK and ICK).

	Standing Position			On bicycle Position	
Data	Mean	sd	Student t-test	Mean	sd
Phase Angle(°)	6.8	0.4	0.231	6.8	0.4
BCMl/H²	11.9	0.9	0.513	11.8	0.9
FFM (kg)	67.4	4.7	0.945	67.1	4.9
FFM (% W)	91.9	2.4	0.979	91.4	2.3
FM (kg)	6.0	1.9	0.945	6.3	1.8
FM (%W)	8.1	2.4	0.979	8.6	2.3
LBM (kg)*	62.0	3.2	0.016	61.6	3.2
LBM (% W)*	84.9	7.2	0.018	84.2	6.8
BMC (kg)*	3.4	0.2	0.010	3.3	0.2
% BMC (/FFM kg)	3.7	0.3	0.086	3.6	0.3
BCMl Leweling (kg)	37.6	2.8	0.544	37.2	3.2
BCMl Leweling (%)	51.2	1.7	0.505	50.6	1.9
Muscle Mass Wang (kg) *	34.0	2.1	0.034	33.6	2.3
Muscle Mass Wang (%) *	46.4	1.3	0.039	45.8	1.1
Vt (liter)**	47.9	2.8	0.003	47.2	2.8
Ve (liter)***	20.7	1.3	0.001	20.5	1.3
Ve (% Vt)	43.3	0.6	0.616	43.3	0.6
Vi (liter)*	27.2	1.6	0.014	26.7	1.6
Vi (% Vt)	56.7	0.6	0.616	56.7	0.6
Hydration of Fat Free Mass (%)*	71.1	15	0.039	70.4	1.5
Hydration of body (%)**	65.3	2.0	0.005	64.4	1.5
Ve/Vt	0.4	0.0	0.616	0.4	0.0
Ve/Vi	0.8	0.0	0.633	0.8	0.0
Re/Rinf	1.4	0.0	0.586	1.4	0.0
Estimation of Plasmatic Volume Vp (liter)**	3.7	0.2	0.004	3.6	0.2
Estimation of Vred_cell (liter)**	2.4	0.1	0.004	2.3	0.2
Estimation of Vblood (liter)**	6.0	0.3	0.004	5.9	0.3
Rinf (ohm)**	356.8	21.1	0.005	364.6	20.2
Re (ohm)***	487.2	24.5	0.001	497.5	28.3
Reactance 50 kHz (ohm)	48.0	2.5	0.459	48.6	3.8
Resistance 50 kHz (ohm)***	401.4	22.0	0.001	410.1	21.7

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TBK Kotler (mmol)*	4030.9	230.9	0.034	3983.1	253.7
Estimation of ECENa (mmol/l)	169.7	2.8	0.938	169.7	2.6
Estimation of ECK (mmol/l)	9.7	0.3	0.966	9.7	0.3
Estimation of ICK (mmol/l)	141.0	1.4	0.124	141.4	1.8

Table 2: comparison between body composition data measured in standing position and on bicycle position. *, P t-test<0.05; **, P t-test<0.01; ***, P t-test<0.001

We propose that in order for measures of bioimpedance for cyclists, it is more reliable to take the reference of monitoring in position on the bike. Of course, to make an assessment of body composition, the most relevant is to do it in standing position.

3.2 – Is there a difference between Fat Mass measured by a foot-to-foot impedancemeter and a wrist-ankle impedancemeter?

Table 3 shows mean and standard deviation of FM obtained with our two impedancemeters FFI and WA. We observe that there is a non significant difference (P=0.183) between the two percentage of fat mass before the exercise.

Data	Mean	sd	Student t-test
% FM of FFI	9.4	3.1	0.183
% FM of WA	8.1	2.4	

Table 3: comparison of percentage of FM obtained by the Foot-To-Foot (FFI) and the Wrist-Ankle (WA) impedancemeters.

3.3 – Is there a difference between Fat Mass measured before and after exercise?

Table 4 summarises the measurements of FM made before and after exercise obtained by our two impedancemeters. Our protocol was made for not inducing loss of FM during exercise but for inducing a loss of water. We can observe that the two impedancemeters indicate a significant loss (P<0.001) of FM. This shows that we can assume that bioimpedance cannot be reliable to indicate FM after an effort, water lost affects FM, in kg or in percentage. However, we want to indicate that equations of Z-Metrix® were not yet developed to be used in standing position. They were developed to be used in lying position. Maybe with the future new equations for standing position, that type of problem will disappear. If not, we shall have to modify our equation to integrate that point.

Data	Mean	sd	Student t-test
FM of FFI (kg)	-1.1	0.6	0.00005
FM of WA (kg)	-1.4	0.5	7.10^{-6}
% FM of FFI	-1.5	0.8	0.00007
% FM of WA	-1.9	0.7	0.00001

Table 4: comparison between FM measured before and after exercise, obtained by two types of impedancemeter, a foot-to-foot (FFI) and a wrist-ankle (WA) impedancemeter.

3.4 – Is it possible to obtain reliable bioimpedance data during monitoring exercise?

Figure 1 shows the monitoring of reactance (X) during an isometric contraction of leg at 50% of Maximal Voluntary Contraction (MVC). Despite the contraction of the muscle, we obtain a stable reactance with our WA impedancemeter. We verified that during an effort without movement, our bioimpedance data are stable.

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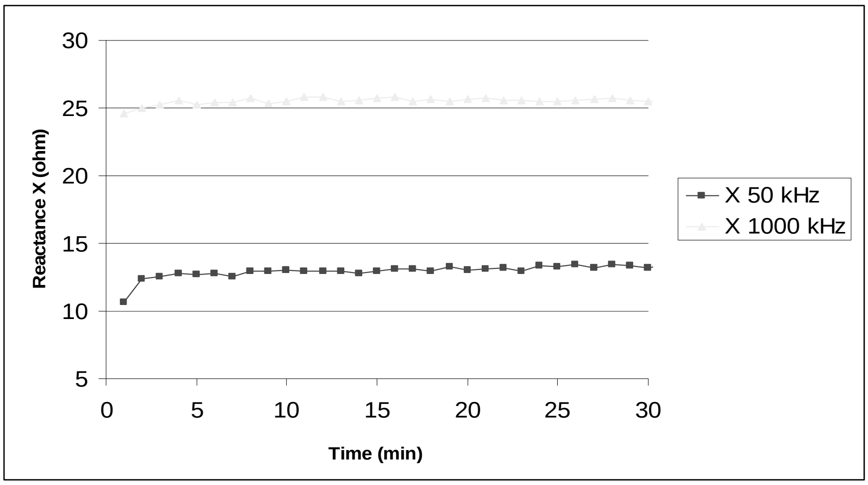

Figure 1: monitoring of reactance (ohm) during an isometric contraction (50% MVC)

Figure 2 shows the monitoring of phase angle, during our exercise, in two representative subjects of hard training cyclists HT (about 4 hours of training, 6 times per week) and low training cyclists LT (about 4 hours of training, 2 times per week). Peaks correspond to maximal effort (maximal heart rate). During the first part about 9 minutes of warm up, the phase angle is more o less stable, till the beginning of rising to the maximal heart rate. We observe that HT subject have a significant variation of phase angle during the peak but this is not the case in the LT subjects. That shows that HT have the capacity of increasing the activity of cells'membranes. We can suppose that permits them to avoid cramps for example. It may be noted that the second time of rising to maximal heart rate, the body seems to need less metabolic activity to achieve the same heart rate.

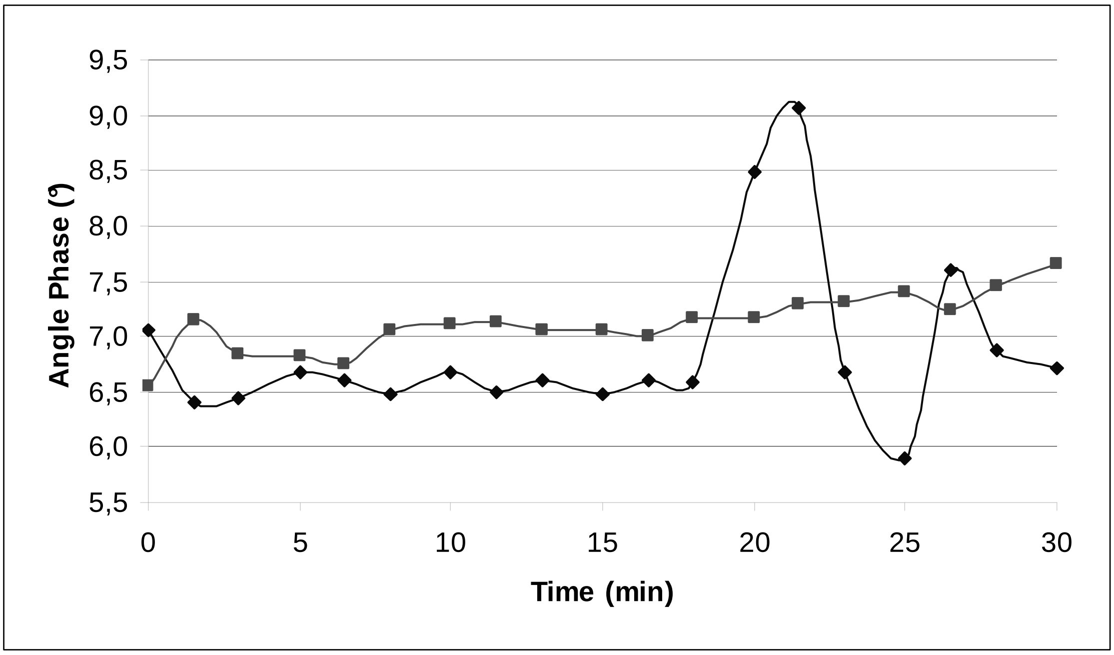

Figure 2: monitoring of phase angle (°) during exercise. In blue, data of hard training cyclist and in red, data of low training cyclist. Peaks correspond to maximal effort (maximal heart rate).

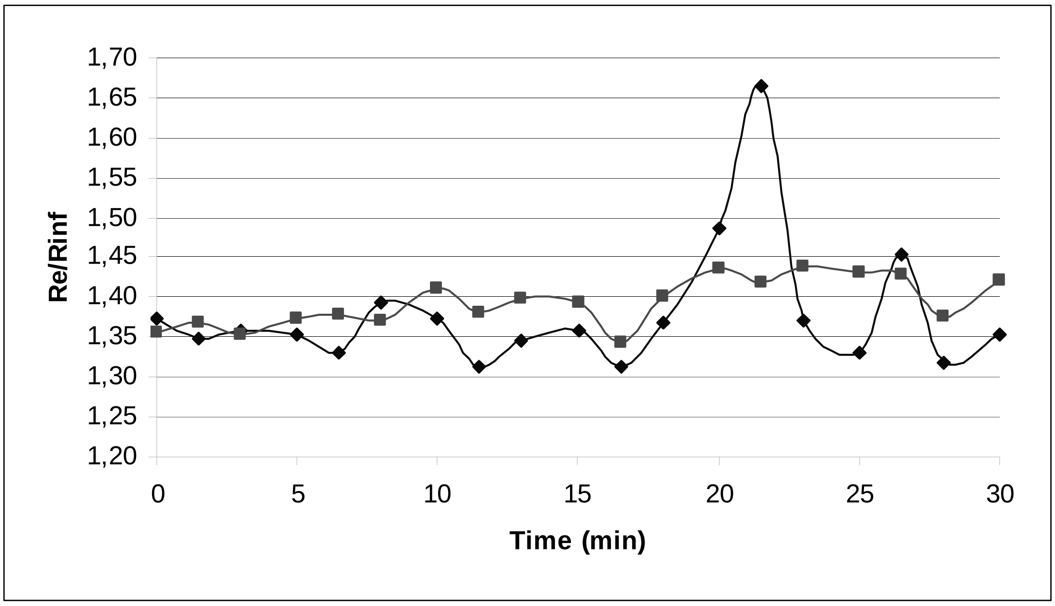

Figure 3: monitoring of phase angle (°) during exercise. In blue, data of hard training cyclist and in red, data of low training cyclist.

Figure 3 shows the variations of Re/Rinf ratio during exercise. We see the increase of the ratio during the peak, corresponding to maximal heart rate. We observed the same phenomenon for the two subjects but it's more significant for HT subject. We can deduct that during the peak of activity, fluids pass from extracellular compartment to intracellular compartment, that's why the reactivity of cells'membranes is very important.

4- Conclusion

We saw that positioning on bike change current lines and thus data of body composition. Then to have a reference during monitoring body composition of cyclists, it would be more relevant to take the reference data when the subject is on the bicycle.

We saw that equations to obtain FM after an exercise have to be modified to be reliable. Before these modifications, bioimpedance have to be used before an effort.

We observed that bioimpedance can be relevant to monitor cyclists even if they are in movement.

Bioimpedance permits to follow the cells'membranes activity during a peak of activity, showing the difference between a hard and low training subject. We showed the fluids'movement from extracellular to intracellular compartment during maximal activity.

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