



**HAL**  
open science

## Leg electrical resistance predicts venous blood viscosity and hematocrit

Emmanuelle Varlet-Marie, Laurent Vachoud, Bénédicte Marion, Céline Roques, Thibault Fidani, Constance Chevalier, Jacques Mercier, E. Raynaud, Jean-Frédéric Brun

### ► To cite this version:

Emmanuelle Varlet-Marie, Laurent Vachoud, Bénédicte Marion, Céline Roques, Thibault Fidani, et al.. Leg electrical resistance predicts venous blood viscosity and hematocrit. *Clinical Hemorheology and Microcirculation*, 2019, 71 (4), pp.397-402. 10.3233/CH-199003 . hal-02112117

**HAL Id: hal-02112117**

**<https://hal.science/hal-02112117>**

Submitted on 4 Jun 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**Leg electrical resistance predicts venous blood viscosity and hematocrit.**  
**Emmanuelle Varlet-Marie <sup>a,b</sup>, Laurent Vachoud <sup>c</sup>, Bénédicte Marion <sup>a,b</sup>, Céline Roques <sup>a,b</sup>, Thibault Fidani <sup>d</sup>, Constance Chevalier<sup>d</sup>, Jacques Mercier <sup>d</sup>, Eric Raynaud de Mauverger <sup>d</sup>, Jean-Frédéric Brun <sup>d</sup>**

*<sup>a</sup>Institut des Biomolécules Max Mousseron (IBMM) UMR 5247 CNRS, Université de Montpellier, Ecole Nationale Supérieure de Chimie de Montpellier, France*

*<sup>b</sup>Laboratoire de Biophysique & Bio-Analyses, Faculté de Pharmacie, Université de Montpellier, France*

*<sup>c</sup>UMR QualiSud , Faculté de Pharmacie, Université de Montpellier, France*

*<sup>d</sup>U1046 INSERM, UMR 9214 CNRS « Physiopathologie & Médecine Expérimentale du Cœur et des Muscles - PHYMEDEXP », Unité d'Explorations Métaboliques (CERAMM), Université de Montpellier, Département de Physiologie Clinique, Hôpital Lapeyronie CHRU Montpellier, France*

Corresponding author : [j-brun@chu-montpellier.fr](mailto:j-brun@chu-montpellier.fr)

We previously reported that whole body bioelectrical impedance analysis (BIA) measurements are correlated to some hemorheologic factors, suggesting a relationship between viscosity factors and electric properties of flowing blood not only *in vitro* but also *in vivo*. Recently we reported that with segmental BIA (analyzing the body considered as composed of 5 cylinders) predictive equations for various determinants of blood viscosity were closer than for the whole body. Another widely used BIA technique uses leg-to-leg impedance measurements so that two cylinders (the two legs) are analyzed. We investigated whether impedance measured with this technique (Tanita TBF-300) is also a predictor of blood viscosity factors. From viscometric measurements performed on venous blood drawn in recreative athletes over the range of shear rates 1 to 6000 s<sup>-1</sup> (RHEOMETRE Anton Paar CP 50-1), we found a correlation between leg-leg resistance at 50 kHz (Rx[50kHz]) and blood viscosity at 1000 s<sup>-1</sup> ( $\eta_{1000} = 0.0051 \text{ Rx}[50\text{kHz}] + 1.3265$ ;  $r=0.521$   $p=0.028$  yielding a prediction of  $\eta_{1000}$  (Bland Altman plot : bias 0.05 [RANGE -0.24; 0.34]). Neither plasma viscosity nor the red cell rheology index « k » of Quemada's model are correlated with Rx[50kHz], but hematocrit (Hct) does ( $\text{Hct} (\%) = 0.0217 \text{ Rx}[50\text{kHz}] + 33.783$ ;  $r=0.480$   $p=0.044$ ) yielding a prediction of Hct (Bland Altman plot : bias -0.11, [range -1.67; 1.45]). The discrepancy between actual and predicted Hct is also correlated with resistance at 50 kHz ( $r=0.575$   $p=0.031$ ) as does the discrepancy between actual and predicted Hct /viscosity ratio ( $r=-0.651$   $p=0.006$ ). Therefore, as other previously studied methods, leg to leg BIA predicts viscosity, suggesting that blood rheology may influence the passage of an electric current in the legs.

**Running title:**

**Keywords:** segmental bioelectrical impedance, hematocrit, Myrenne aggregometer, Red blood cell aggregation, electrical conductance, light transmission

## **1. Introduction**

Bioelectrical impedancemetry (BIA) can be used *in vitro* to evaluate hematocrit [5] and red cell aggregation [1]. This technique is also widely applied in medicine for the assessment of body composition [2, 6, 7, 10, 15].

Actually, recent research on BIA has shown that this technique was able to measure an even wider range of parameters. We repeatedly reported with whole body impedance measurements correlations between electrical properties of the whole body (impedance, resistance, reactance) and some hemorheologic factors (hematocrit, whole blood viscosity and plasma viscosity, red cell rigidity and RBC aggregation) [3, 19].

One of the limits of such studies investigating the links between whole body impedance and the rheological properties of blood was the shape of human body, which barely can be modeled as a cylinder. By contrast, on cylindrical segments *i.e.*, arms, legs or trunk studied separately, these relationships can be more clearly evidenced, as we recently reported with newly developed BIA devices [20].

Another widely used BIA is leg to leg, which actually measures the circulation of electricity through the two legs, *i.e.*, a cylindrical model of a part of the body [4]. Whether this simple and usual measurement provides a reflect of hemorheological parameters as previously shown with other techniques is unknown.

Therefore this study was undertaken in order to investigate whether the electric properties of the two legs are correlated to measurements of blood viscosity.

## **2. Subjects and methods**

### **2.1. Study subjects**

Characteristics of subjects are shown in Table 1. The study was approved by the local Institutional Ethics Committee and the competent European authority (N°EudraCT: 2016-002742-23). Written informed consent was obtained from each volunteer prior to his enrolment in the study. They were included in a study aiming at investigating whether simultaneous administration of low doses of epoetin-alpha (Binocrit) and growth hormone (Genotonorm) have an effect on erythropoiesis or on the aerobic performance. Consequences for the anti-doping screening are also studied.

## **2.2. Bioelectrical impedance measurements**

Bioimpedance analysis as performed with the Tanita TBF-300A body composition analyzer which utilizes "foot-to-foot" BIA technology (Bio-electrical Impedance Analysis) to make determining internal body composition. This device measures impedance of the body to an alternative electric current of a frequency of 50 kHz and an intensity of 500  $\mu$ A. It can measure impedances ranging from 150 to 900 ohms [16].

## **2.3. Hemorheological *in vitro* measurements**

Venous blood samples for hemorheological measurements (7 ml) were drawn in the cubital fossa with a large needle, with potassium EDTA as the anticoagulant in a vacuum tube (Vacutainer).

Viscometric measurements were then performed over the range of shear rates 1 to 6000  $s^{-1}$  with the RHEOMETRE Anton Paar CP 50-1 (Anton Paar Germany GmbH, Hemuth-Hirth-Strasse 6, D-73760 Ostfildern / Germany) [11-13].

Hematocrit was measured together with other hematological markers with the Coulter analysis.

## 2.6. Statistics.

Results are presented as mean  $\pm$  the SEM. A value of  $p < 0.05$  was considered as significant. Comparisons were made with nonparametric tests. Pearson coefficients of correlation were tested by least square fitting.

## 3. Results

As shown on Fig. 1 there was a correlation between leg-leg resistance at 50 kHz ( $R_x[50\text{kHz}]$ ) and blood viscosity at  $1000 \text{ s}^{-1}$  ( $\eta_{1000} = 0.0051 R_x[50\text{kHz}] + 1.3265$ ;  $r=0.521$   $p=0.028$  yielding a prediction of  $\eta_{1000}$ . The Bland Altman plot (Fig. 2) of this relationship shows an agreement with a bias of 0.01 and range of  $\pm 0.2$ .

As shown on Fig. 3, hematocrit is also correlated to leg-to-leg resistance at 50 kHz.

( $\text{Hct} (\%) = 0.0217 R_x[50\text{kHz}] + 33.783$ ;  $r=0.480$   $p=0.044$ ) yielding a prediction of Hct (Bland Altman plot : bias -0.11, [range -1.67; 1.45]). The discrepancy between actual and predicted Hct is also correlated with resistance at 50 kHz ( $r=0.575$   $p=0.031$ ) as does the discrepancy between actual and predicted Hct /viscosity ratio ( $r=-0.651$   $p=0.006$ ).

Neither plasma viscosity nor the red cell rheology index « k » of Quemada's model are correlated with  $R_x[50\text{kHz}]$ .

## 4. Discussion

This study evidences correlations between BIA crude leg-to leg measurements at 50kHz, and both hematocrit and whole blood viscosity at high shear rate.

These results are in line with our preceding papers cited in the introduction. They lead to think that those previously reported correlations between BIA and viscosity factors were not spurious, because they are regularly found again with various devices and on various populations. We assume that in a narrow cylinder such as the leg the structure of circulating blood (hematocrit, whole blood viscosity) may influence the passage of an electric current by increasing reactance. Whether this may provide a reliable window on hemorheology remains of course to be studied, because the correlation is not so close.

BIA instruments based on leg-to-leg impedance are attractive alternatives to the whole-body BIA model, but studies have shown discrepancies in the evaluation of fat mass compared to reference techniques (around  $\pm 2$  kg) [8-9, 14, 17-18].

The reason for this reported poor reliability is obvious: only one part of the body is assessed, and no information about the electric properties of trunk and arms is given. Therefore, a recent review concludes that these individual prediction errors are too great for the methods to be used accurately at the individual level for assessing body fat [4].

Actually we previously performed a comparison of fat mass measurements with this method compared to DEXA and found a not so bad agreement ( $r=0.95$   $p<0.001$ ), which leads to think that the simplicity of the method, although it is accompanied by a moderate loss in precision, does not make it invalid. In addition correction parameters developed for this device can improve its accuracy [16].

By contrast this limitation which is presented as a flaw for body composition assessment is an advantage for our purpose to detect a relationship between the electric properties of a cylindrical segment of the body and blood rheology. Leg-to leg impedance measurements are very easy and inexpensive. This approach is simpler than the multifrequency segmental one presented in one of our previous studies. It can be thus easily tested on large samples.

Further testing of this approach is needed. This study suggests that the previously reported correlations between whole body BIA and viscosity factor were probably not spurious, and that in a narrow cylinder such as the arm the structure of circulating blood (hematocrit, red cell aggregation) may influence the passage of an electric current by increasing reactance. Whether this may provide a reliable window on hemorheology remains of course to be studied.

## **5. Conclusions**

Therefore, as other previously studied methods, leg to leg BIA predicts viscosity, suggesting that blood rheology may influence the passage of an electric current in the legs.

The fact that we regularly observe these relationships between viscosity factors and *in vivo* body impedance with various methods of viscometry and BIA suggests that these findings are not spurious and have physiological relevance.

**Acknowledgements:** The authors affirm that they have no disclosure of interest concerning the issue investigated in this paper. This study was presented as a poster during the conference of the European Society for Clinical Hemorheology and Microcirculation, the International Society of Clinical Hemorheology and The International Society of Biorheology (ESCHM-ISCH-ISB-2018), Krakow, Poland, July 2-6, 2018.

**List of symbols:** Hct: Hematocrit; RBC: red blood cell; SEM: standard error on the mean.



## References

- [1] O. K. Baskurt, M. Uyklu and H. J. Meiselman, Time Course of Electrical Impedance During Red Blood Cell Aggregation in a Glass Tube: Comparison With Light Transmittance, *IEEE Transactions on Biomedical Engineering*, **57(4)** (2010), 969-978.
- [2] J.-F. Brun, M. Guiraudou, C. Mardemootoo, A. Traoré, I. Raingeard, A. Chalançon and A. Avignon, Validation de la mesure segmentaire de la composition corporelle en comparaison avec la DEXA: intérêt de la mesure de la masse grasse tronculaire, *Science & Sports* **28** (2013), 158-162.
- [3] J.-F. Brun, E. Varlet-Marie and J. Mercier, Whole body bioimpedance as a mirror of the influence of hemorheological factors on electric properties of blood: a step forward with Hanai's mixture conductivity theory, *Series on Biomechanics* **25(1-2)** (2010), 100-104.
- [4] A. C. Buchholz, C. Bartok and D. A. Schoeller, The validity of bioelectrical impedance models in clinical populations, *Nutrition in Clinical Practice* **19(5)** (2004), 433-446.
- [5] N. Devarasu and G. Sudha, Dual frequency bioelectrical impedance analysis to estimate hematocrit for prognosis of dengue fever in Indian children, *Biomedical Engineering / Biomedizinische Technik* (2018), in Press.
- [6] M. Guiraudou, L. Maimoun, J.-M. Dumas, M. Julia, I. Raingeard and J.-F. Brun, Composition corporelle mesurée par impédancemétrie segmentaire (BIAS) et performance de sprint chez les rugbymen, *Science & Sports* **30(5)** (2015), 298-302.

- [7] M.Y. Jaffrin and H. Morel, Body fluid volumes measurements by impedance: A review of bioimpedance spectroscopy (BIS) and bioimpedance analysis (BIA) methods, *Medical Engineering & Physics* **30(10)** (2008), 1257-1269.
- [8] L. Jartti, M. Hakanen, U. Paakkunainen, P. Raittinen and T. Ronnema, Comparison of hand-to-leg and leg-to-leg bioelectric impedance devices in the assessment of body adiposity in prepubertal children: the STRIP study: Special Turku coronary Risk factor Intervention Project, *Acta Paediatrica* **89** (2000), 781–786.
- [9] S. A. Jebb, T.J. Cole, D. Doman, P.R. Murgatroyd and A.M. Prentice, Evaluation of the novel Tanita body-fat analyser to measure body composition by comparison with a four-compartment model, *British Journal of Nutrition* **83** (2000), 115–122.
- [10] S.F. Khalil, M.S. Mohktar and F. Ibrahim, The theory and fundamentals of bioimpedance analysis in clinical status monitoring and diagnosis of diseases, *Sensors* **14(6)** (2014), 10895-10928.
- [11] J. Lauger, M. Bernzen, K. Wollny and G. Raffer, New developments for temperature control for rotational rheometers, *Annual Transactions of the Nordic Rheology Society* **10** (2002), 147-153.
- [12] J. Lauger, P. Heyer and G. Raffer, A new device for controlling the true gap size in real time during rheological testing, *Proceedings of the 4th Pacific Rim Conference on Rheology*, August 7~11, Shanghai, China; (2018).

- [13] J. Lauger and S. Huck, Real controlled stress and controlled strain experiments with the same rheometer, *Proceedings of the XIIIth International Congress on Rheology*, Cambridge, United Kingdom **3** (2000), 10-13.
- [14] S. Lazzer, Y. Boirie, M. Meyer and M. Vermorel, Evaluation of twofoot-to-foot bioelectrical impedance analysers to assess body composition in overweight and obese adolescents, *British Journal of Nutrition* **90** (2003), 987–992.
- [15] U. Mulasi, A.J. Kuchnia, A.J. Cole and C.P. Earthman, Bioimpedance at the bedside: current applications, limitations, and opportunities, *Nutrition in Clinical Practice* **30(2)** (2015), 180-193.
- [16] P. Poon and D. Poon, Correction Factor on The Interpretation of The Tanita Body Composition Analyzer Goal Setter TBF-300, *Canadian Journal of Diabetes*, **37(2)**, (2013), S281.
- [17] C.E. Spencer, J.M. Lingard and M.A. Bermingham, Comparison of a footpad analyser with a tetrapolar model for the determination of percent body fat in young men, *Journal of Science and Medicine in Sport* **6** (2003), 455–460.
- [18] R.Y. Sung, P. Lau, C.W. Yu, P.K. Lam and E.A. Nelson, Measurement of body fat using leg to leg bioimpedance, *Archives of Disease in Childhood* **85** (2001), 263–267.

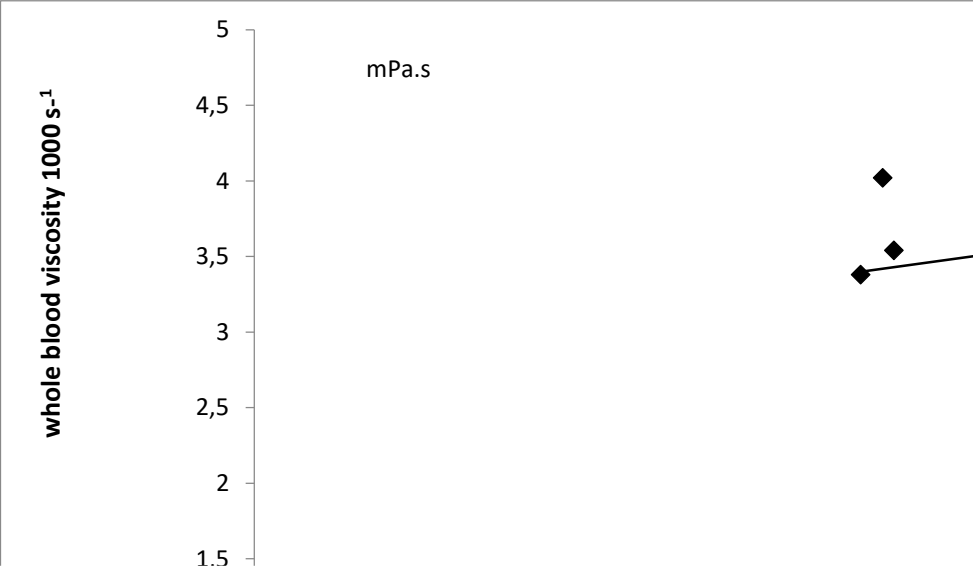
- [19] E. Varlet-Marie, I. Aloulou, J. Mercier and J.-F. Brun, Prediction of hematocrit and red cell deformability with whole body biological impedance, *Clinical Hemorheology and Microcirculation* **44(4)** (2010), 237-244.
- [20] E. Varlet-Marie, C. Joré and J.-F. Brun, Segmental bioelectrical impedance analysis (SBIA) and blood rheology: Reducing the gap between in vivo and in vitro? *Clinical Hemorheology and Microcirculation* **64(4)** (2016), 603-611.

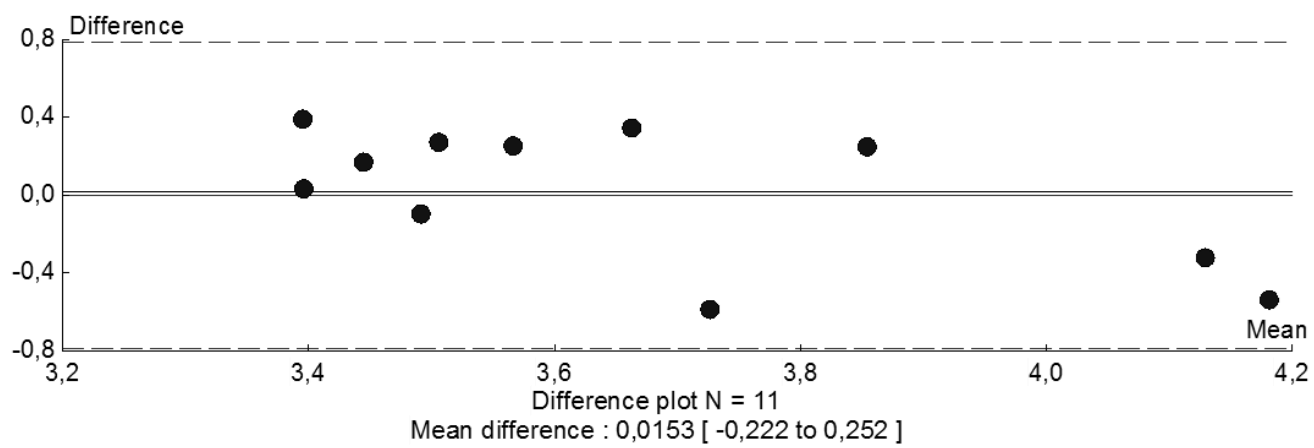
**Table 1.** Clinical characteristics of the 11 subjects of the study (mean + SEM).

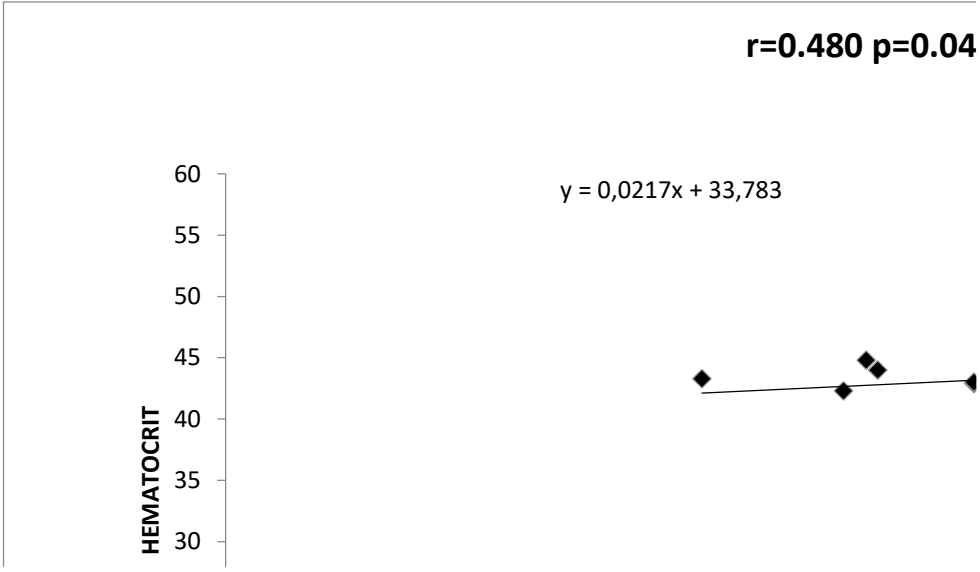
---

age (years)	22.20±2.82
weight (kg)	78.77±9.53
height (cm)	175.62±5,91
body mass index (kg/m <sup>2</sup> )	25.4±2.35
hematocrit (%)	43.71±2.13

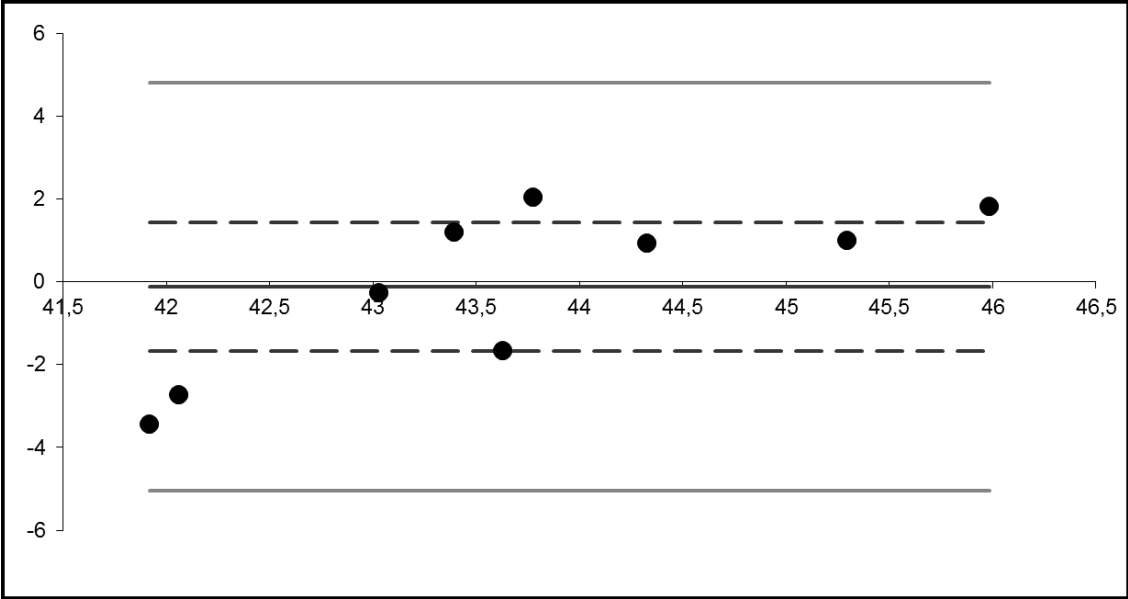
---











**Fig. 1.** Correlation between blood viscosity at  $1000 \text{ s}^{-1}$  and leg-to-leg resistance at 50 kHz.

**Fig. 2.** Bland Altman graph showing the agreement between blood viscosity at  $1000 \text{ s}^{-1}$  and leg-to-leg resistance at 50 kHz.

**Fig. 3.** Correlation between hematocrit and leg-to-leg resistance at 50 kHz.

**Fig. 4.** Bland Altman graph showing the agreement between hematocrit and its prediction from the correlation with leg-to-leg resistance at 50 kHz presented on Fig. 3. Bias  $-0.11$ ; [range  $-1.67$ ;  $1.45$ ].