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Bioelectrical Impedance Vector Analysis (BIVA) for the monitoring of body composition in pregnancy

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Abstract

Background/Objectives: during pregnancy, body composition alterations can be considered as markers of complications and in this context, a non-invasive and low-cost method such as Bioelectrical Impedance Vector Analysis (BIVA), can be employed to monitor such changes. This study aimed at identifying body compartments trend during physiological pregnancy. **Subjects/Methods**: classic and specific BIVA variables have been measured in a sample of 37 pregnant women approximately every 4 weeks of gestation and once postpartum. Researchers used both longitudinal and cross-sectional approach. The first case included data of women from the 11th to the 15th week along with data from the 28th to the 32nd week of gestation. The cross-sectional approach regarded two more specific moments (11th-12th weeks and 30th -31st weeks) and data within two months postpartum. **Results**: the longitudinal approach showed a significant decrease in classic BIVA variables (R/H, Xc/H, Z/H $p<0.001$) and a shortening of the vector, pointing out that TBW and hydration increased significantly. Specific vector length increased significantly, indicating a physiological gain of FM% ($p<0.01$). The cross-sectional approach showed lower values of R/H, Xc/H, Z/H between 12th-13th and 30th-31st weeks ($p<0.01$), while in the postpartum period values tended to those registered at the beginning of pregnancy. No changes have been found for the phase angle in both approaches, indicating that ECW/ICW ratio remained constant. **Conclusions**: among physiological pregnancies, bioelectric values showed a coherent trend and these results represent a first contribution to support routine exams, leading to an early detection of anomalous values potentially correlated to pathologies.

1. Introduction

Pregnancy is a particular period in a woman's life and is characterised by many changes, being for most women a physiological event. In several cases, complications may arise in the course of pregnancies, ranging from minor discomforts to severe diseases (1). For example, in Piedmont (Italian North-West region), the percentage of pregnancies considered as low risk, and thus defined physiological, fluctuated from 70.2% up to 87.7% during the period 2006-2016 (2). However, in Italy, almost 30% of pregnancies starting without any risk can eventually show complications such as hypertension, with an incidence of 3-5% (3) and gestational diabetes mellitus (GDM) with a prevalence of 4.7% (4). The whole duration of pregnancy should indeed be monitored carefully, ensuring the early identification of risk factors (5). Regularly monitoring of pregnancy can be quite valuable to identify potential complications at their inception: at this purpose, national and international clinic protocols (1,6) include routine exams such as blood count, ultrasounds, blood pressure, glucose checks and Gestational Weight Gain (GWG) controls, which are checked through the Body Mass Index (BMI, kg/m^2) according to the guidelines of the Institute of Medicine (6). Besides these controls, previous studies have shown the usefulness of evaluating body composition, in terms of body fluids, fat mass and fat-free mass: this yields additional information regarding the status of mother and foetus and the advancement of pregnancy (7). A fast, cheap and reliable technique to assess body composition is Bioelectrical Impedance Analysis (BIA), that is applied either to monitoring physiological conditions or to identifying body composition changes potentially related to metabolic complications or pathologies (8). BIA measures the bioelectrical variables of resistance and reactance (9). The data processing can be carried out using different approaches depending on the targeted outcomes. In particular, conventional BIA analysis, which has been frequently employed to estimate body liquids during pregnancy, results in an important method as reported by many authors who highlighted differences between physiological pregnancies and those showing complications, especially regarding Total Body Water (TBW) (10–17). Excessive expansion of the volume of TBW could be caused by oedema and lead to hypertension (18), while a progressive reduction in TBW has been linked to gestational hypertension and preeclampsia (12,15) as well as to low birth weight and adverse outcomes of the pregnancy (16,19,20). Moreover, an excessive gaining in adipose tissue (and thus FM) could be related to GDM, preterm birth, foetal macrosomia and increase of number of Caesarean section (21). As pregnancy is a particular condition in which the balance of body liquids is very different from the physiological state of the general population (TBW increases as reported by Lukaski et al. (22)), the quantitative estimation of FFM and other compartments through conventional BIA cannot be quantified through population-specific equations which assume a physiological condition of 73% body hydration (19) .

Besides that, a qualitative analysis is offered by Bioelectrical Impedance Vector Analysis (BIVA) (23) . The classic BIVA approach standardises resistance and reactance for height (23) and has proved to be a useful method to monitor TBW (8,24). A further approach, defined "*specific* BIVA", adjusts resistance and reactance for height and for cross-sectional areas, and has been found to be more accurate in the evaluation of FM% (24–26). Both classic and specific BIVA have demonstrated to correctly detect variations of ECW/ICW (Extra Cellular Water/ Intra Cellular Water) compared to dilution techniques (21). To our knowledge, few studies have used classic BIVA to assess body composition during pregnancy, whereas specific BIVA has never been used. In 2007, Lukaski and collaborators validated the use of classic BIVA for the assessment of hydration during gestation in a cohort of 15 women, using isotope dilution as a reference (22). They identified classic BIVA as a valid method to monitor body hydration during pregnancy: thus, the vector progressively reduces its length during the last two trimesters of gestation, indicating physiological liquid increase during pregnancy. Rodríguez Atristain et al. (21), highlighted an increase in body fat deposition and in TBW amount in each pregnancy trimester, in a sample of Mexican women. Massari et al. (27) outlined the case of a woman who experienced paroxysmal supraventricular tachycardia (SVT) that was intercepted and monitored also thanks to the use of BIVA, which had shown liquid depletion.

The present study aimed at identifying body composition changes during pregnancy through both longitudinal and cross - sectional approaches, applying either classic or specific BIVA in a sample of Caucasian pregnant women. The expected findings could be used as a reference for the monitoring of physiological changes and for the early identification of anomalies potentially related to pathologies.

2. Materials and methods

Data were collected in the Ambulatory of Obstetrics and Gynaecology of the Hospital "Ospedale Civile E. Agnelli" (Pinerolo, Italy) from March 2018 to January 2019. The study was approved by the Bioethics Committee of the University of Turin in February 2018 (Protocol n. 127246/06-03-2018), it was conducted in accordance with the Declaration of Helsinki for human studies of the World Medical Association (28) and the recruitment of women was on a voluntary basis. Participation involved signing an informed consent, following a detailed verbal explanation and a written memorandum of the guidelines regarding measurements was offered to each participant. The data presented in this study are available on request from the corresponding author.

2.1 Study design

Inclusion criteria involved European women with a physiological pregnancy at the end of the first trimester. Exclusion criteria were the presence of previous pathologies or those that occurred during the early weeks of gestation. Assessments started at the end of the first trimester, on the occasion of routine clinical exams in the ambulatory. Women were measured approximately every 4 weeks of gestation, for a minimum of 5 appointments during pregnancy and once postpartum. During every appointment, clinical, personal and socio-demographic information was collected for each woman, and anthropometric and bioelectrical measurements were taken.

The research was developed as follows: (i) monitoring the body composition during the advancement of pregnancy; (ii) excluding all the cases of pathologies occurring during the development of pregnancy; (iii) identifying bioelectrical variables differences and thus physiological body composition changes through a longitudinal and a cross-sectional approach.

The longitudinal approach included data related to two distinct periods of gestation: from the 11^{th} to the 15^{th} week, which represents the stage in which the risk of an abortion occurring is considered overcome and the foetus is healthy and growing (1), along with data from the 28^{th} to the 32^{nd} week, the phase in which the pathologies caused by pregnancy start manifesting and are consequently diagnosed and treated, while the foetus is completing its most crucial moment of development (1).

The cross-sectional approach included data of the central two weeks of the abovementioned periods (weeks 12^{th}-13^{th} and weeks 30^{th}-31^{st} respectively), and data within two months postpartum, in order to analyse body composition in three key moments of the course of pregnancy. The choice of these specific periods of gestation has been taken in accordance to the gynaecological suggestions (author: CV) (1).

2.2 Anthropometric, bioelectrical measurements and data interpretation

Anthropometric measurements were collected according to the international standard and literature guidelines: weight and stature in addition to body circumferences such as waist, calf (29), and arm (30). Bioelectrical variables were measured using the phase sensitive BIA 101 analyser (50 kHz, 400μA) and mono-use electrodes Biatrodes (by Akern S.r.l., Pontassieve, Florence, Italy). Every woman was asked to remove any metal object, and subsequently measured wearing only underwear, making sure to have an empty bladder and skin free of oils or body lotions, according to the standard procedures introduced by the National Institutes of Health (NIH) (9). Participants lay on their back in a medical non-conductive surface (bed), and bioelectrical tissue values were measured on the right hemisoma between the ipsilateral wrist and anklebone prominences (metatarsus – metacarpus region). Distance between electrodes pair was 5 cm. The analysis of bioelectrical variable was performed according to classic BIVA (23,31), correcting variables for stature (R/H, Xc/H and Z/H) and according to specific BIVA (25,26) which corrects for both stature and cross-sectional areas (A/L), where A is estimated as 0.45 mid-arm area + 0.10 waist area + 0.45 calf area, yielding specific resistance, reactance and impedance (Rsp, Xcsp and Zsp). Arm, waist and calf areas were estimated by the formula $C^2/4\pi$, where C (m) is the circumference of the respective segment. Phase angle was calculated as follows: $\varphi = \arctan Xc/R \cdot (180/\pi)$ and is not affected by the correction shown for classic and specific BIVA. In both BIVA approaches, as first shown by Piccoli et al. (23) for classic BIVA, impedance can be considered as a vector, whose interindividual variability is plotted in a Cartesian plane, defined by a bivariate distribution of its component (R/H and Xc/H or Rsp and Zsp). Three tolerance ellipses are considered, respectively the areas including 50%, 75% and 95% of the whole reference population. Inter-group comparisons can be realised using confidence ellipses. For classic BIVA, vectors moving parallel to the major axes indicate progressive changes in tissue hydration (dehydration corresponds to long vectors and hyperhydration to short vectors), while vectors moving parallel to the minor axes indicate alterations in the phase angle (greater values on the left), which means changes in the cellular mass (24). For specific BIVA, vectors moving parallel to the major axes indicate progressive changes in Fat Mass percentage (FM%) (more FM% corresponds to long vectors) and vectors moving parallel to the minor axes give the same information as classic BIVA.

2.3 Data Analysis

The normality of the data was verified using the Shapiro-Wilk test. Statistical analysis was carried using IBM SPSS Statistics (version 25). Paired and independent samples Student's t-tests regarding bioelectrical and anthropometric variables were performed in order to analyse differences according to the longitudinal and cross-sectional approach, respectively. BIVA Software (31) and specific BIVA software (www.specificbiva.unica.it) were used to draw tolerance ellipses and confidence ellipses and performing independent and paired T^2 Hotelling tests. Statistical significance was accepted for $p<0.05$.

3. Results

Of the 37 women involved in the study, 20 carried out a healthy and physiological pregnancy and were thus considered for data analysis. The mean age of the sample was 31.95±4.02 years. Measurements suitable for the longitudinal approach, according to the study design's criteria, were 24 (12 women were assessed twice: in the period 11th-15th weeks and in the period 28th-32nd weeks of gestation, supplementary table 1 and supplementary table 2). For the cross-sectional study, we considered 27 measurements (9 measurements in the weeks 12^{th}-13^{th}, supplementary table 3; 8 measurements in the weeks 30^{th}-31^{st}, supplementary table 4; 10 measurements postpartum, supplementary table 5) referable to the entire sample of 20 healthy women. Postpartum data analysis was possible only in the context of cross-sectional study as not every woman considered in the longitudinal approach respected the last appointment.

3.1 Longitudinal approach

Differences between the two periods (11^{th} to the 15^{th} week and 28^{th} to the 32^{nd} week) regarding anthropometric and bioelectrical variables were calculated (Table 1). Weight significantly increased by approximatively 10 Kg, corresponding to a significant increment of BMI. Classic BIVA variables (R/H, Xc/H, Z/H) decreased significantly, despite the great dispersion of data shown by the SD values. The lowering of classic BIVA variables refers, according to Piccoli et al. (23), to a significant increase in TBW. Specific BIVA variables, conversely, increased significantly during gestation for Xcsp ($p<0.05$) and even more significantly for Zsp and Rsp ($p<0.01$), pointing out a physiological increase of FM% (24) with a particularly high SD. Phase angle did not change, indicating that the ECW/ICW ratio did not change between the two moments of pregnancy.

The classic BIVA ellipse did not overlap with the origin of the axis, indicating a significant change in body composition ($p<0.001$). In particular, the vector was shortening, thus confirming that TBW and hydration increase during the two periods of gestation considered (Figure 1A-1B). The specific BIVA vector significantly increased its length ($p<0.001$), confirming the increase of FM%.

3.2 Cross-sectional approach

The comparison between different groups of women in three gestational moments (12^{th}-13^{th} weeks, 30^{th}-31^{st} weeks, and postpartum) showed that classic BIVA variables (R/H, Xc/H, Z/H) were lower ($p<0.01$) in the week 30^{th}-31^{st} with respect to the week 12^{th}-13^{th} of pregnancy (Table 2).

This result highlighted an increase in TBW and hydration during pregnancy (for R/H, Xc/H, Z/H $p<0.01$ between 12^{th}-13^{th} and 30^{th}-31^{st} weeks) as detected in the longitudinal study as well. The cross-sectional study also highlighted the tendency to the normalisation of body hydration in the postpartum period whose data tended to reach values close to 12^{th}-13^{th} weeks (none of classic BIVA values showed statistical significance), as also emerged in the confidence ellipses analysis (Figure 2).

4. Discussion

Pregnancy is a significant and particular moment in women's life. It involves physiological modifications in the function of organs, tissues and mechanism as well as in body composition and bioelectrical properties of tissues. In order to monitor anomalies that could potentially lead to complications, BIVA represents a valid, non-invasive method to assess body composition status and its changing. However, the literature presents few reference information concerning the trend of bioelectrical variables during pregnancy. In the stretch of time between the end of the first and third trimester, as shown by both the longitudinal and the cross-sectional approach, TBW and body hydration increased significantly, as indicated by classic BIVA (lower values of R/H, Xc/H and Z/H). These results are consistent with those of Lukaski et al. (22) and Rodríguez Atristain et al. (21). In the cross-sectional study, postpartum classic bioelectrical values resulted higher, reaching conditions close to the beginning of pregnancy (12^{th}-13^{th} weeks) as already shown in the study of Lukaski et al. (22), although considering different gestation weeks and periods. Thus, the increase in hydration during pregnancy appears to be easily observable with BIVA approach, whose transferability and replicability in a context of routine monitoring are relatively easy to guarantee. Consequently, it is interesting to amplify these observations by assessing the ECW/ICW ratio, documented by the phase angle. Literature results concerning the phase angle in physiological pregnancies did not highlight significant changes between the end of the first and the third trimester either in the longitudinal (according with Lukaski et al., 2007 (22) and with Berlit et al., 2013 (14)) or in the cross-sectional approach (according to Rodriguez-Atristain et al., 2016 (21)). In the same way, in our study an unchanged phase angle was confirmed in the data from the pregnancy and postpartum measurement. Hence, during the advancement of pregnancy, even though TBW and body hydration increase, the ECW/ICW ratio can remain constant. Indeed, the literature shows an increase of ICW in the third trimester of pregnancy, along with the increase of ECW, that could be associated with the lack of ICW/ECW changes (17). This finding suggests how PA can be used as a potential marker to monitor the displacement of TBW in compartments occurring for example in preeclampsia or hypertension (7). Thus, the early identification of ECW/ICW displacement through phase angle may be adopted as a fast, non-invasive and practical support tool for the early diagnosis and potential treatment of those pathologies. Regarding the choice of methods to interpret bioelectrical data, the value of classic BIVA must be underlined, mainly for the assessment of TBW and hydration, while specific BIVA was particularly useful to monitor FM% alterations. Indeed, the longitudinal approach showed a significant increase of FM% during physiological pregnancy (Rsp and Zsp $p<0.01$; Xcsp $p<0.05$). This result demonstrates that it is possible to monitor if the weight gain is excessive or insufficient in terms of FM% and thus potentially leading to complications and/or pathologies such as gestational diabetes mellitus (7). Concerning both TBW and FM%, such health prevention-oriented interpretations were made possible by a qualitative approach (BIVA), which seems to be more suitable for the body composition monitoring in this kind of context. To our knowledge, this is the first study to use the complementarity of phase angle, classic BIVA, and specific BIVA in order to monitor body composition changes during pregnancy. An analogous approach has already been applied for the body composition assessment in other fields such as sport (24,32) the identification of sarcopenia and sarcopenic obesity (33) as well as in paediatrics (34).

4.1 Strengths and limits

Through our approach, which for the first time employs the analysis of bioelectrical changes in terms of classic, specific BIVA and phase angle during pregnancy, it is possible to expect its application to routine monitoring of pregnancies thanks to its replicability, non-invasivity, rapidity of use and moderate price, that allows the early identification of anomalies and complications. The limits, on the other hand, concern the lack of availability of postpartum measurement. Moreover, the number of physiological pregnancies could be increased. With a broader sample, it could be possible to estimate possible differences by age and primigravidae/multigravidas in relation to a distinctive balance in body composition.

4.2 Conclusions and future perspectives

According to our results, women tend to increase their TBW and FM% during pregnancy but tend to recover their characteristics during postpartum. The combination of the analysis of phase angle, of classic BIVA and specific BIVA is an effective, fast, low-cost and non-invasive method to monitor body composition changes during pregnancy. As pregnancy-correlated pathologies/complications are linked to inadequate modifications of body composition, especially in term of body fluids, the constant monitoring through BIVA, together with routine exams, could lead to an early diagnosis and treatment.

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6. Conflict of Interest

The authors declare no conflict of interest.

7. Author Contributions

AM contributed to the conceptualisation of the study design, revised the literature, conducted the research, was responsible for data analysis and interpretation and wrote the original article draft.

CV contributed to the conceptualization of the study design, provided resources, helped in the medical interpretation of results and supervised the development of the entire research.

AG contributed to the data analysis and curation.

SS contributed to the data analysis, curation and helped in data interpretation.

EM contributed to the validation of the methodology, helped in data interpretation and reviewed the entire manuscript.

MMC: contributed to the conceptualization of the study design, provided resources, helped in data analysis and interpretation of results, supervised the development of the entire research and reviewed the manuscript from the original draft.

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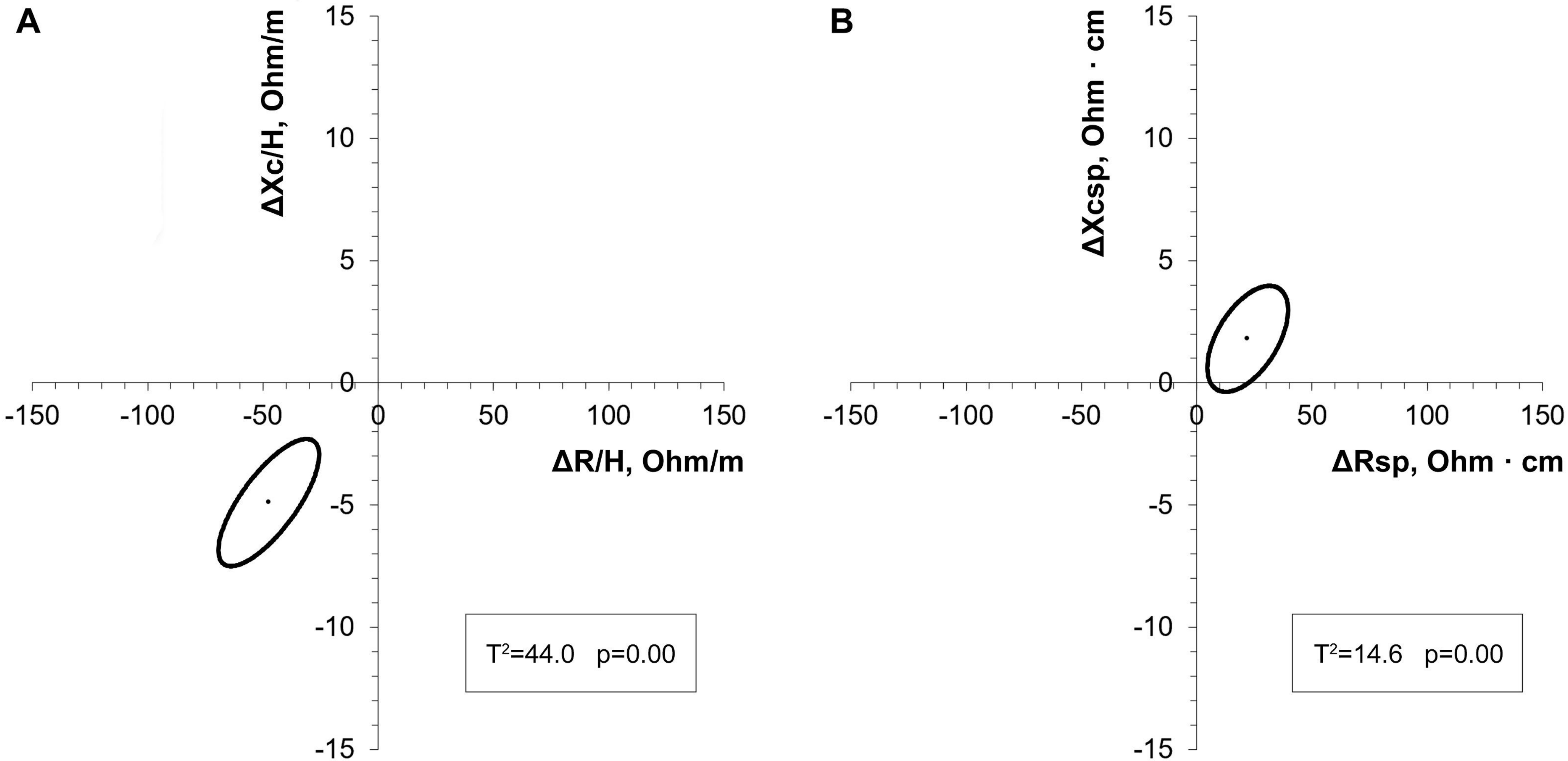
A
ΔXc/H, Ohm/m
ΔR/H, Ohm/m
T²=44.0 p=0.00
B
ΔXcsp, Ohm · cm
ΔRsp, Ohm · cm
T²=14.6 p=0.00
15
10
5
0
-5
-10
-15
-150
-100
-50
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50
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150

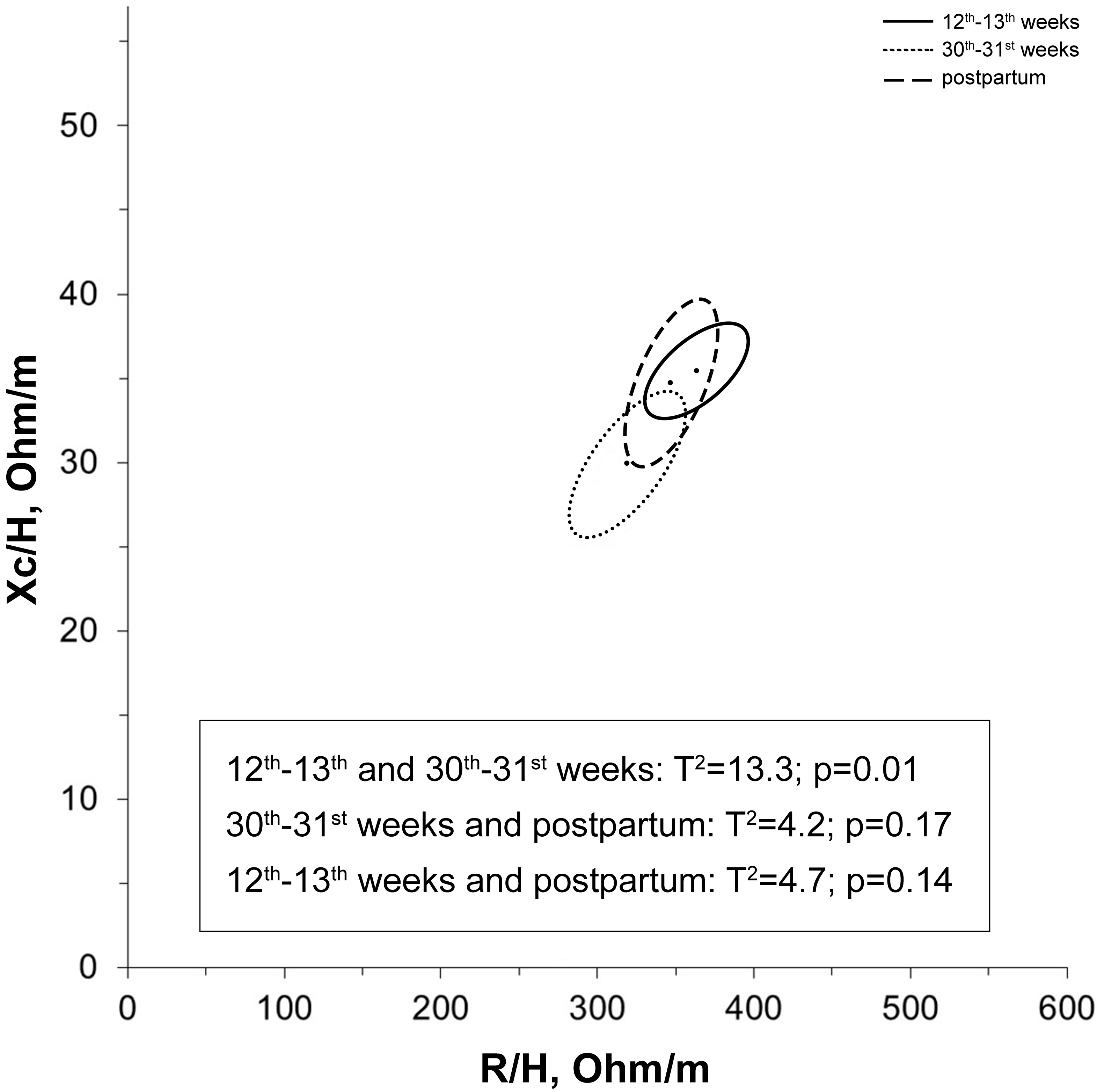
12th-13th weeks
30th-31st weeks
postpartum
12th-13th and 30th-31st weeks: T2=13.3; p=0.01
30th-31st weeks and postpartum: T2=4.2; p=0.17
12th-13th weeks and postpartum: T2=4.7; p=0.14
Xc/H, Ohm/m
R/H, Ohm/m
0
10
20
30
40
50
0
100
200
300
400
500
600

Table 1. Results of the longitudinal study on 12 healthy pregnant women: difference (Δ) between weeks 28th-32nd and 11th-15th of anthropometric and bioelectrical variables (mean and SD) and significance in bold.

		Δ between 28th-32nd weeks and 11th-15th weeks		Paired Student's t-test results	
		Mean	SD	t	Significance
Weight (kg)		9.88	2.53	13.51	**p<0.001**
BMI (kg/m²)		3.76	0.87	14.94	**p<0.001**
Classic BIVA	R/H (Ohm/m)	-47.45	25.21	-6.52	**p<0.001**
	Xc/H (Ohm/m)	-4.94	2.98	-5.75	**p<0.001**
	Z/H (Ohm/cm)	-47.70	25.32	-6.53	**p<0.001**
Specific BIVA	Rsp (Ohm· cm)	22.07	20.19	3.79	**p<0.01**
	Xcsp (Ohm· cm)	1.80	2.51	2.49	**p<0.05**
	Zsp (Ohm· cm)	22.14	20.23	3.79	**p<0.01**
Phase Angle (°)		-0.06	0.33	-0.59	0.57

Table 2. Results of cross-sectional study on anthropometric and bioelectrical variables (mean and SD) of healthy pregnant women during weeks 12th-13th, weeks-30th-31st, and within two months postpartum. Significance in bold.

Independent Student's t-test results						
	12th-13th and 30th-31st weeks		**30th-31st weeks and postpartum**		**12th-13th weeks and postpartum**	
	t	**p value**	**t**	**p value**	**t**	**p value**
R/H (Ohm/m)	3.18	**p<0.01**	-1.60	0.13	1.94	0.07
Xc/H (Ohm/m)	3.42	**p<0.01**	-2.05	0.06	0.80	0.44
Z/H (Ohm/cm)	3.20	**p<0.01**	-1.62	0.13	1.94	0.07
Rsp (Ohm· cm)	0.15	0.88	-0.68	0.51	-0.52	0.61
Xcsp (Ohm· cm)	0.64	0.53	-1.27	0.22	-0.91	0.38
Zsp (Ohm· cm)	0.16	0.88	-0.69	0.50	-0.52	0.61
Phase Angle (°)	0.81	0.43	-1.22	0.24	-0.63	0.54