The perspectives of BIA application for beef carcass composition analysis and meat quality evaluation

Z. Bohuslavek*
Department of Electrical Engineering and Automation, Faculty of Engineering, Czech University of Life Sciences, Prague, Czech Republic.
*E-mail: bohuslavek@tf.czu.cz.

Introduction

The investigation of the passive electrical properties of biological tissues with a idea of utilizing such properties for biomedical applications began at the beginning of the 20th century. The appeared One example is the suggestion of Hugo Fricke [1] to classify tumorous tissue by its electrical properties. All methods which aim at the characterization of the passive electrical properties of biological objects are currently grouped together with the term *bioimpedance* (BI) *methods*. Excellent reviews can be found in the literature [2,3,4]. Using of these methods for quality assessment of agricultural and food products is coming into research, and finally in exploitation some time after (at the end of the 20th century), see [5,6,7]. Many possible applications quoted (of the cited) diagnostic methods have first of all the following superiorities: α) require only low-cost instrumentation, β) are easily applicable in practice. The here described application is searching whether bioelectrical impedance analysis (BIA) can accurately predict changes in beef carcass composition. There is also a suggested way of how to improve accuracy of this analysis and how to also use carcass segment conductivity in evaluation of meat quality.

Objectives

This study aimed to investigate the effects of replacing a beef carcass bioimpedance analyzer for measurement at an abattoir line, at the location of carcass flaying. And in the following to analyze methodically whether it will be possible to acquire high quality regressive equation of estimation of beef carcass composition and meat quality with analysis by means of subsequent measuring of conductivity of fat free mass.

Methodology

A) Measurement with a beef carcass bioimpedance analyzer at an abattoir line

Based on past experiments with BIA method, there was developed a beef carcass bioimpedance analyzer for measurement at an abattoir line, at the location of carcass flaying. The selection of this location removed the negative effect of temperature drop in beef carcass and the negative effect of the follow-up technological processes. The measurement was done by four electrode instruments with a full automatic data transfer. The photo on the Fig. 1 shows an arrangement of the electrode sensing head with electronics on the carcass which has not been dissected yet, it means at the location of carcass flaying.

Description of measuring method and device. The identical method of measurement with area elastic electrodes provided on surface Cu-foil about area 30 cm2 was used for measurement of BIA. In the measuring system were implemented the automatic measurement of electrodes distance and the control measuring process from the place of operator of telescopic electrode adapter. The first version of this appliance has been described already by [8]. For the circuit layout of the measuring system, see Figure 2.

Reference values – have been acquired from two sources: from video image analysis (VIA) and from partial dissection of loin (PDL). Both sources have been described in [8], [9], and therefore in brief only: VIA - the images of cross-sections between 8th and 9th rib were taken after cooling carcasses and the software LUCIA 3.52 practiced the image processing analysis and area of muscle tissue and area of fat one were measured.

Partial dissection of loin. The dorsal parts – loins (caudal from 8th rib) incl. backbone were cut from the beef carcasses and weighted (SV). These parts were consecutively deboned and again weighted (S). Finally all other tissues (adipose etc.) were removed the *longissimus lumborum et thoracis* muscles and these muscles were weighted too (MLL).

Output values of the analyzer. Data obtained from impedance analysis were replenished by calculating values, for examples the "D2/Rp, D2/Xcp" as electric volume [5,6,10,11], where Rp is parallel resistance [ohm] and Xcp is parallel reactance [ohm] of tissue. The results of experimental measurement were processed using the WINSTAT application. Estimation formulae have been calculated with multiple stepwise regression analysis.

B) Other possibilities how to increase the BIA accuracy when making assessment of beef carcass composition and market quality.

1. Model – equivalent electrical circuit of a biological tissue and finally of a beef carcass

Cells that are taken for fundamental tissue construction elements are a complicated complex of organic and mineral substances. The cell outside is framed with a membrane which is electrically developing capacitance characteristics within the limits of 0.1 to 3 μF/cm^2 (10^{-3} to 3.10^{-2} F/m) and surface resistance characteristic up to 10 kΩ.cm^2 (up to 1 Ω.m^2). Inside the cell, there is an intracellular liquid, and an extracellular liquid is outside. Both liquids are of specific resistance 1 to 30 Ω.m a relative permitivity $\varepsilon_r \approx 80$.

The tissue with specific conductance σ and permittivity ε is possible to be modelled with a parallel RC network, where the resistance R is proportional to the reciprocal value of the specific conductance σ and where the capacitance is proportional to the permittivity ε.

2. Beef carcass assesment by means of BIA – FFM and FM content

The BIA methods are most properly worked trough and used in the human medicin and therefore the following analysis is derived from these sources and quoting them. The simplest electrical model for the whole body is that of a conducting cylinder with height *h*, volume *V* and conductivity κ . This cylinder represents the lean tissue volume. As the impedance *Z* between top and bottom of such a cylinder is given by

$$Z = h^2 / \kappa V = R + jX, \qquad R\ldots resistance[\Omega], \quad X\ldots reactance[\Omega] \tag{1}$$

an inverse linear relationship between lean tissue volume and the impedance between two electrodes can be assumed. According to eq. (1) many investigators reported a linear correlation between ECV and 1/ *Z*; for reviews see e. g. [10,11,12]. Extra - and intracellular volume (ECV, ICV).

3. Assessment of body (carcass) composition - fat and fat free mass compartments

Established BIA methods in the human medicin are based on a two-compartment model which subdivides the body into fat and fat-free mass (FFM). The fat mass or the percentage of body fat relative to the body mass (BF) is more important for the health state diagnostic . As the tissue conductivity depends on the content of conducting fluids, adipose tissue does not contribute much to the impedance when measured between the extremities. Rather the impedance is strongly correlated with the FFM as reported by [13], [10], [11]. In contrast to body fluid determination structural models have not been frequently applied for the prediction of BF from BI-data. An alternative model which combines body fluid estimation with the estimation of the FFM has been suggested in [14]. In both cases the body fat is calculated by subtracting the estimated FFM from the total body mass, see [12].

4. How to eliminate the outside factors measurable with difficulties (temperature, age and gender, race, precedent sustenance program etc.)

Different carcass temperature is remarkably affecting the measured impedance values. If the BIA is taken on the end of the line as it is usual, the carcassc temperature drop is different in accordance with the actual temperature of the abattoir environment and of the individual carcass weight. The measuring of the carcass average temperatures is technically difficult and therefore this affect is to be eliminated with practising the BIA on the abattoir line entry where the temperature drop is relatively small and therefore either the differences in this drop are relatively small.

The other above quoted factors, the influence of which is difficult for being measured and formulated, are mostly affecting the conductivity of carcass tissue. Thus a possibility of measuring the conductivity of muscular tissue on an exactly anatomically defined place on beef carcass with an acceptable method is available as well as to use then this qantity as the correction one in regression equations of fat free mass estimation and of fat mass of beef carcasses. Even more perfect estimation is possible to be reached at the measurement of components of the complex conductivity κ :

$$\kappa = \sigma + j\omega\varepsilon_0\varepsilon_r = \sigma' + j\sigma'' \tag{2}$$

where … σ , σ' *= real component of onductivity,* σ'' *= imaginary component of conductivity*

ω *= angular frequency of BIA current,* $\varepsilon_0, \varepsilon_r$ *= free-space and muscular tissue permittivity*

The measured compoments of complex conductivity cold help us aven at the followinig meat quality assessment. They are the reasons why the following research is orientated in this way.

Result & discussion

The correlations between the impedance quantity and reference VIA values have been researched at first – e.g. the images of cross-sections between 8th and 9th rib and partial dissection of loin (PDL). The obtained correlations were not higher than those from the precedent measurements on the end of the abattoir line, being represented with a little bit lower average level. The carcass weight showed the highest dependence level on the $D^2/100Rp$ index, namely in the value r = 0,86. Relatively lower correlation degree was found between *longissimus lumborum* muscle weight (MLL) and BIA variables, for the D2/Xcp100k index, the correlation coefficient resulted on r = 0,81 and for the D2/Rp100k index, it was r = 0,80. The area of cut MLL (cm2) has been taken from the picture analyse and then multiplied with 10% carcass length. This theoretical MLL (cm3) capacity showed relatively high correlation dependence between the impedance indexes D2/Xcp100k – r = 0,89 and Xcp100k – r = 0,86.

It is possible to suppose that reaching the only medium correlation proportions have been caused with a very variable content of ventriculus - measured on the place before evisceration.

Regression analysis was orientated to find the best regression model (equation) for estimating selected references values – weight (MLL) (kg) of the longissimus lumborum et thoracis muscles and for the muscle tissue area (cm2) derived from the VIA - the images of cross-sections between 8th and 9th rib. The best calculated regression equations are summarized in Table 1. MLL weight is more exactly estimated by the model Nr.1 where coefficient of determination r2 = 0,9 and coefficient of the correlation r = 0.95 was achieved. The best regression equation for the estimation of area of the muscle tissue (cm2) by VIA shows satisfactory coefficient of the determination r2 = 0,0,85. In all equations the significance level of the independent variables is P<0.05, but mostly P<0.005.

Table 1. Regression models for beef carcasses (n = 85)

Model no.	Dependent variables	Independent variables	Equations	r^2 / r^{**}	SD^*
1.	MLL [kg]	D D2 /Xcp100k CW	MLL = 1.44 + 1.297 * 10^{-2} * CW – 2.289*10^{-2} * D – 1.907*10^{-2} * D2 /Xcp100k	0.95/0.90	.5
2.	muscle [cm2]	D D2 /Rp100k CW	muscle = 111.34 + 2.592 * CW + 0.50167* D2 /Rp100k – 4.480 * D	0.92/0.85	10.2

** [RSD]…stand. error of estimation* *r^2 / r^{**} … coefficient of correlation / determination;*

D ….distance (cm) *D2 /Xcp100k …impedance index volume (cm2/ohm)* *CW …carcass weight (kg)*

Figure 1. A picture of electrode sensing head with electronic positioning on the beef carcass.

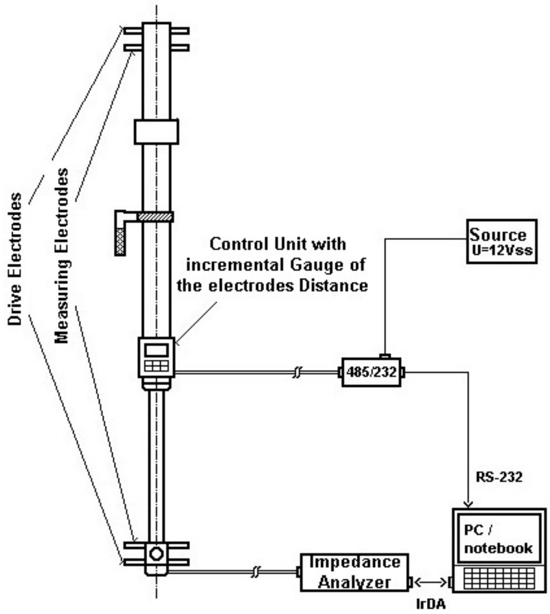

Figure 2. Schematic diagram of measuring system.

Conclusions

At the conclusion, it is possible to state that the results of the experiment confirmed that the BIA method is suitable for practical use in the instrument evaluation of beef carcasses. The localization of sensing electrodes is useful for being looked for in a frame of following research so that the negative influence caused with variable ventriculus content is to be minimized. Hereafter, the research will be focused for locating a suiting method for conductivity assessment of a selected muscle (a contactless method will be the best).

References

Fricke, H, Morse S., (1926): The electric capacity of tumors of the breast. J. Cancer Res.10: 340-376.

Bourne, J.R., (1996) : Bioelectrical impedance techniques in medicine. Crit. Rev. Biomed Eng., 1996.

Holder, D. (1993): Clinical and physiological applications of electrical impedancetomography. UCL Press, London, 1993.

Webster J.,G. (1990.), Electrical impedance tomography. Adam Hilger, Bristol, 1990.

Swantek P.M., Creschaw J.D., Marchello M.J., Lukaski H.C. (1992): Bioelectrical impedance a non-destructive method to determine fat-free mass of live market swine and pork carcasses. J. Anim. Sci., 70, 169–177.

Hegarty R.S., McPhee M.J., Oddy V.H. (1998): Prediction of the chemical composition of lamb carcasses from multi-frequency data. Brit. J. Nutr., 79, 169–176.

Balcaen A.,Seynaeve M., Claeys E., De Smet S. (2002): Bioelectrical impedance measurements on beef carcasses for the prediction of carcass lean. In: Proceeding 48th ICoMST, August 25–30, Rome, Italy, Vol. II, 748–749.

Bohuslavek Z., (2005): The on line measurements of beef carcass quality and composition by means of the bioelectrical impedance analysis, In: Proceeding 51st International Congress of Meat Science and Technology , Baltimore, Maryland USA, 1789-1792.

Bohuslavek Z., Pipek, P., Malý J. (2002): Use of BIA method for the estimation of beef carcass composition – weight of longissimus lumborum muscle, ratio of muscle tissue and fat in loin cross-section. Czech J. Anim. Sci., 47, 387–394.

Lukaski, C.H. - Johnson, E.P. - Bolonchuk, W. W., (1985): Assessment of fat free using bioelectrical impedance measurements of the human body. The American Journal of Clinical Nutrition 41, 1985, p. 810-817.

Lukaski,C.,H., (1987): Methods for the assessment of human body composition: traditional and new. The American Journal of Clinical Nutrition; 46, p. 537-556.

Kushner R.,F.(1992): Bioelectrical Impedance Analysis: A Review of Principles and Applications. J Am Coll Nutr, 11: 199-209, 1992.

Segal KR, Van Loan M, Fitzgerald PI, Hodgdon JA, Van Itallie TB. (1988): Lean bodymass estimation by bioelectrical impedance analysis: a four-site cross-validationstudy. Am. J. Clin. Nutr. 47: 7-14.

Van Loan MD, Withers P, Matthie J, Mayclin PL.,(1993): Use of bio-impedance spectroscopy (BIS) to determine extracellular fluid (ECF), intracellular fluid (ICF), total body water (TBW), and fat-free mass (FFM). In: Human Body Composition: In Vivo Methods, Models, and Assessment. Ellis KJ, Eastman JD (eds.). Plenum, New York.