Prediction of carcass composition by impedance spectroscopy in lambs of similar weight

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Abstract

Previous research on impedance measurements for the prediction of carcass composition was predominantly carried out on animals that varied widely in body weight, breed, or sex. The high accuracy for the estimated lean or fat mass was mainly obtained by including the body weight in the regression equations. The objective of this study was the prediction of carcass composition in lambs of similar weight. We used 70 male German Merino Mutton lambs and 70 male German Blackheaded Mutton lambs with 35 and 45 kg live weight each. Impedance measurements with different electrode placements were carried out in vivo and on carcasses 20 min and 24 h postmortem. The carcass composition was ascertained by dissection of the left carcass side into lean, fat, and bone. \( R^2 \)-values for prediction of lean mass by impedance and body weight ranged between 0.11 and 0.71 within breeds and weight groups and between 0.84 and 0.89 in the total material. Lean percentage was estimated with \( R^2 \) between 0.18–0.48 within breeds and weight groups. The corresponding values for the total material varied from 0.23 to 0.37. We conclude that the impedance method is not suitable for the prediction of lean or fat percentage, neither in lambs of similar weight nor in heterogeneous animals.

Keywords: Impedance; Carcass composition; Lamb

1. Introduction

Impedance spectroscopy gains increasing interest for the prediction of the body composition in humans and animals. For constant resistivity, the quotient \( L^2/Z \) (\( L = \) distance of the voltage electrodes, \( Z = \) impedance) theoretically allows the assessment of the frequency dependent volume of body compartments involved in current flow. This is the extracellular fluid at low frequencies and the total body water at high frequencies. The prediction of lean, fat or fat free mass becomes likely, because these compartments are highly correlated with the water content.

In livestock, the mass of lean or fat was commonly estimated by impedance, body weight, and electrode distance as independent variables in regression equations (Hegarty, McPhee, Oddy, Thomas, & Ward, 1998; Marchello, McLennan, Dhuyvetter, & Slanger, 1999a; Swantek, Marchello, Tilton, & Crenshaw, 1999). A high accuracy resulted from consideration of only the body weight, especially if it exhibited a high variability, because the tissue masses increased with body weight. The impedance method was scarcely investigated in animals of similar body weight. In order to investigate the significance of the impedance for body composition we applied this method in lamb groups of definite weight,
breed, and sex. In practice, the carcass quality of such homogeneous groups must be evaluated, e.g., in breeding systems with a weight dependent performance test. Contrary to other authors, who commonly measured the impedance in the frequency domain, we used the time domain impedance, which allow a high speed of measurement and simpler technical equipment (Altmann, Pliquett, Suess, & von Borell, 2004). Furthermore, we tested different electrode placements and the repeatability. The results of this work should also allow conclusions for the suitability of the impedance method for carcass grading. Within the European Union, the carcass grading system for pigs is based on lean percentage, for beef and sheep on the body conformation and fat content as well as fat distribution. Therefore, the carcass dissection into tissues was choosen as a reference method for impedance measurements.

2. Materials and methods

2.1. Animals

The protocol for this study was approved by the Animal Care Committee of the veterinary district office. We used 70 male lambs of German Mutton Merino (MM) and 70 male German Blackheaded Mutton lambs (BM). The lambs of each breed were divided into two groups: 35 lambs of 34–36 kg and 35 lambs of 44–46 kg live weight. They were weaned at three months of age and fed with concentrates (10.2 mJ NE/kg) and hay ad libitum. The animals were weighed weekly and feed-deprived for 24 h when they reached the final weight. The lambs were slaughtered according to normal industrial procedures immediately after the in vivo impedance measurements.

2.2. Impedance measurements

Time domain based impedance measurements were used in this experiment. We demonstrated in further studies (Altmann et al., 2004), that this method is adequate for the commonly used measurements in the frequency domain. It is more practicable for a great number of animals due to simplicity and high speed of measurement.

2.2.1. Technical setup

A continuously running square wave oscillator supplied an offset free current with an amplitude of ±100 μA into the outer electrodes (current electrodes) of the four-electrode interface. The voltage appearing at the inner electrodes (voltage electrodes) was monitored using a high impedance differential probe. Both, the current and the voltage were traced by a digital oscilloscope THS720 (Tektronix, Bracknell, UK). The traces were stored in a laptop-computer for further processing. In order to avoid additional noise and parasitic oscillations, one of the outer electrodes carried the current amplifier while the other outer electrode had an internal pull down resistor of 1 kΩ. The inner electrodes were both attached to a FET-input buffer amplifier. All coaxial connections to the impedance measurement device were matched to 50 Ω. Syringe needles with 0.3 mm diameter and a length of 3 mm (ventral electrode placement) or 25 mm (dorsal electrode placement) were used as electrodes for in vivo measurements, while 0.95 mm – needles with a length of 35 mm were used for the carcasses.

2.2.2. Electrode placements for in vivo measurements

The in vivo measurements were done after 24 h feed withdrawal with electrode placements in three different ways (Fig. 1). Dorsal: Current electrodes 3 cm from the dorsal midline at the first coccygeal vertebra and 5 cm cranial from the tip of the shoulder blade. Voltage electrodes 3 cm from the dorsal midline 5 cm cranial of first coccygeal vertebra and at the tip of the shoulder blade. The lamb was fixed in a box and the head was arrested. Ventral I: Current electrodes near the right ossa carpi and near the left M. semimembranosus close to the tuberositas tibiae, voltage electrodes in the right armpit and beside the left teat. The lamb lay on its back and the extremities were restrained. Ventral II: Contralateral to ventral I.

2.2.3. Electrode placements for carcass measurements

Measurements on the whole carcass were done 20 min and 24 h postmortem with the following electrode placements. Dorsal: The same as in vivo. Ventral I: Current electrodes in the right M. flexor digitorum close to the carpal condyle and the left M. semimembranosus close to the tuberositas tibiae, voltage electrodes in the right
M. pectoralis superficialis close to the elbow joint and the left M. semimembranosus close to the condylus lateralis. Ventral II: Contralateral to ventral I.

2.2.4. Number of measurements
The impedance measurement was repeated three times for each electrode variation. The electrodes were newly placed for each measurement to ensure the reproducibility of the entire procedure. Additionally, the distance of the voltage electrodes (L), empty live and carcass weight (W), the rectal and carcass temperature (T) were recorded.

2.3. Carcass analysis
The carcass was trunched at the dorsal midline after the impedance measurements 24h postmortem. The left side was dissected into wholesale cuts without trimming according to the guidelines of the German Agricultural Society (Schepker & Scholz, 1985) and frozen. The cuts were further dissected into lean, fat, and bone after thawing. The thawing loss was added to lean. The percentage of lean, fat and bone of the left carcass side was calculated from the mass of these tissues. We did not determine the chemical composition because of the high correlation to the tissue composition. In further investigations (Altmann et al., 2004), we found a correlation of \( r = 0.92 \) between fat tissue percentage and crude fat and \( r = 0.83 \) between lean percentage and fat-free soft tissue (sum of water and crude protein percentages).

2.4. Mathematical and statistical methods
Both, the current stimulus and the voltage response were fourier transformed. The impedance \( Z \) was calculated by dividing the Fourier transformed voltage by the current. A complex least square fit was used for determination of the characteristic frequency \( f_c \), the real parts of impedance at direct current \( (R_0) \), at infinite frequency \( R_{\infty} \), at the characteristic frequency \( (R_c) \), at 50 kHz \( (R_{50}) \), and the imaginary parts at \( f_c \) and 50 kHz. Additionally, the quotients \( L^2/R_c \) and \( L^2/R_{50} \) were calculated.

Variation coefficients between the single measurements of each electrode placement were calculated for the assessment of repeatability (SAS, Inst. Inc., Cary, NC). We averaged the single measurements for each electrode variation as well as the results of ventral I and II for the prediction of carcass composition. Mean differences between weight groups were examined with the Duncan-test. Partial correlations with empty live or carcass weight and electrode distance as covariates were calculated between impedance and carcass composition within the groups. Furthermore, the data were analyzed by forward regression stepwise procedure. Impedance data, electrode distance, and weight served as independent variables to predict carcass lean tissue. Variables significant at \( P < 0.05 \) at the maximum \( R^2 \) and minimum RMSE (root mean square error) were included in the final equations. Independent variables were removed from the equations at a level \( P > 0.1 \).

3. Results and discussion

3.1. Carcass and impedance data
Table 1 shows the carcass composition for the different breed and weight groups. MM-lambs had a higher percentage of lean and a lower fat and bone content than BM-lambs. The decline of lean content with increasing body weight was almost equal in both breeds and amounts to 2.3% and 2.1%, respectively. The fat percentage increased to 3.9% and 4.0%, respectively. Considerable variability of carcass composition existed within the breeds and weight groups. The variation coefficient for lean percentage was around 5%, for fat percentage around 16%. The presentation of the impedance data is restricted to the real parts of impedance, because the imaginary parts were not relevant for carcass composition (Altmann et al., 2004).

3.1.1. In vivo measurements
The in vivo impedance (Table 2) is lower than the impedance postmortem (Tables 3 and 4). This is mostly due to blood and substances of high water content in the rumen. Ventral electrode placement resulted in some lower values than the dorsal placement. This could be explained by the shorter electrode distance and the greater proportion of rumen and intestines monitored by the ventral electrodes. The differences between the weight groups within the breeds are small with exception

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Carcass composition in different breed and weight groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>MM 35 kg</td>
</tr>
<tr>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Empty live weight (kg)</td>
<td>3.6^a 1.1</td>
</tr>
<tr>
<td>Hot carcass weight (kg)</td>
<td>14.5^a 0.7</td>
</tr>
<tr>
<td>Chilled carcass weight (kg)</td>
<td>14.1^a 0.7</td>
</tr>
<tr>
<td>Lean (kg)</td>
<td>4.4^a 0.3</td>
</tr>
<tr>
<td>Fat (kg)</td>
<td>1.2^a 0.2</td>
</tr>
<tr>
<td>Bone (kg)</td>
<td>1.3^a 0.1</td>
</tr>
<tr>
<td>Lean (%)</td>
<td>63.5^a 2.9</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>17.7^a 3.1</td>
</tr>
<tr>
<td>Bone (%)</td>
<td>18.8^a 1.4</td>
</tr>
</tbody>
</table>

MM, German Mutton Merino; BM, German Blackheaded Mutton; N, number of lambs; abc within a row, means without a common superscript letter differ (\( P < 0.05 \).
Table 2
In vivo impedance of different electrode placements

<table>
<thead>
<tr>
<th>Variable</th>
<th>MM 35 kg</th>
<th>MM 45 kg</th>
<th>BM 35 kg</th>
<th>BM 45 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

Dorsal electrode placement

- $R_0$ (Ω): 62$^a$ 5 61$^a$ 6 63$^a$ 7 64$^a$ 8
- $R_1$ (Ω): 43$^a$ 4 42$^a$ 6 46$^a$ 6 44$^a$ 6
- $R_0$ (Ω): 52$^a$ 5 51$^a$ 6 54$^a$ 6 54$^a$ 7
- $R_0$ (Ω): 49$^a$ 4 48$^a$ 5 50$^a$ 6 50$^a$ 6
- $L$ (cm): 53$^a$ 3 58$^b$ 4 54$^a$ 3 58$^b$ 3
- $L^3/R_0$ (cm$^3$/Ω): 54$^a$ 9 67$^b$ 11 55$^a$ 7 64$^b$ 11
- $L^3/R_{so}$ (cm$^3$/Ω): 57$^a$ 9 72$^b$ 12 59$^a$ 7 69$^b$ 12

Table 3
Impedance of different electrode placements 20 min postmortem

<table>
<thead>
<tr>
<th>Variable</th>
<th>MM 35 kg</th>
<th>MM 45 kg</th>
<th>BM 35 kg</th>
<th>BM 45 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

Dorsal electrode placement

- $R_0$ (Ω): 58$^a$ 7 52$^{bc}$ 6 53$^c$ 8 49$^d$ 5
- $R_1$ (Ω): 44$^a$ 9 37$^{bc}$ 8 39$^c$ 7 37$^d$ 5
- $R_0$ (Ω): 51$^a$ 7 44$^b$ 6 46$^c$ 7 43$^b$ 4
- $R_0$ (Ω): 47$^a$ 7 41$^b$ 6 42$^c$ 6 40$^b$ 4
- $L$ (cm): 50$^a$ 3 55$^b$ 2 51$^c$ 2 56$^b$ 2
- $L^3/R_0$ (cm$^3$/Ω): 50$^a$ 6 70$^b$ 8 59$^c$ 8 73$^b$ 7
- $L^3/R_{so}$ (cm$^3$/Ω): 52$^a$ 7 76$^b$ 9 64$^c$ 8 79$^b$ 7

Table 4
Impedance of different electrode placements 24 h postmortem

<table>
<thead>
<tr>
<th>Variable</th>
<th>MM 35 kg</th>
<th>MM 45 kg</th>
<th>BM 35 kg</th>
<th>BM 45 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

Dorsal electrode placement

- $R_0$ (Ω): 506$^a$ 44 500$^a$ 44 501$^a$ 49 486$^a$ 46
- $R_1$ (Ω): 180$^{bc}$ 21 178$^{bc}$ 21 189$^b$ 25 173$^a$ 21
- $R_0$ (Ω): 346$^a$ 25 336$^{bc}$ 27 345$^b$ 27 330$^b$ 24
- $R_0$ (Ω): 452$^a$ 16 241$^b$ 17 257$^a$ 15 238$^b$ 12
- $L$ (cm): 47$^a$ 1 51$^b$ 1 49$^c$ 2 53$^b$ 2
- $L^3/R_0$ (cm$^3$/Ω): 6$^a$ 0.5 8$^b$ 0.5 7$^c$ 0.6 9$^d$ 0.9
- $L^3/R_{so}$ (cm$^3$/Ω): 9$^a$ 0.6 11$^b$ 0.7 10$^c$ 0.6 12$^d$ 1

MM, German Mutton Merino; BM, German Blackheaded Mutton; N, number of lambs; $R_0$, $R_1$, $R_{so}$, $R_{sc}$ – real parts at direct current, infinite frequency, 50 kHz, and at the characteristic frequency; L, electrode distance; $abc$ within a row, means without a common superscript letter differ (P < 0.05).

growth. The resistance increases with higher electrode distance, but decreases with higher cross-section. In the weight range between 35 and 45 kg, the gain of body length is probably lower than the rise of cross-section area, which counteracts the increase of impedance resulting from the higher fat content. Similar results were reported by Kraetzl, Thiele, Tomaczak, and Kamphues (1993) and Velazco, Morrill, and Grunewald (1999). They observed in pigs and cattle decreasing impedance values in vivo with advancing age. The growth of the digestion tract is unlikely as an explanation, as suggested by Velazco et al. (1999), because this appears on carcasses too. However, the decline in bone content could also be a reason. This behaviour of the impedance illustrates already major problems in prediction of lean or fat content with this method in animals of different body weight. Because the MM-lambs had a significantly higher lean percentage than the BM-lambs, the MM should exhibited lower impedance values at comparable weight. However, this was only apparent, but not significant for the dorsal electrode placement.

3.1.2 Postmortal measurements

The impedance values 20 min postmortem were lower than 24 h postmortem (Tables 3 and 4) due to the higher carcass temperature. Previous investigations showed a further increase up to 48 h postmortem resulting from cell swelling and physiological changes in the cell membranes reducing the volume fraction assessable to low frequency current (unpublished). After 48 h until the 6th
day postmortem, $R_\infty$ remained constant and $R_0$ decreased. These results emphasise the requirement of a fixed time for comparable postmortem impedance measurements. This is especially true for measurements up to 24 h where most of the changes occur. Although the same anatomical points were used for the dorsal in vivo and postmortem measurements, the electrode distance on the carcass was lower due to different posture after hanging. Contrary to in vivo measurements, the postmortem ventral impedance was higher than the dorsal values. This was caused by the substantial higher electrode distance. Additionally, the open abdominal cavity was located directly between the electrodes.

### 3.2. Repeatability of impedance and correlations between electrode placements and measuring time points

The assessment of the real part of the impedance at different frequencies was quite reproducible. The variation coefficients for the single measurements in vivo varied between 3.8% and 9.0%, for postmortem measurements between 1% and 3% (data not shown). The imaginary parts and the characteristic frequency showed a substantially lower repeatability, especially in vivo. Renden, Bilgili, and Sexton (1988), Stanton, Hamar, Johnson, and Fettman (1992) and Swantek, Crenshaw, Marchello, and Lukaski (1992) used single frequency impedance measurements at 50 kHz and confirmed the lower reproducibility of the imaginary part.

Considerable differences were found between the electrode placements in vivo. The correlation was about 0.3 between dorsal and ventral as well as 0.5 between ventral I and ventral II. The lower reproducibility of in vivo measurements influences these results in general. Higher correlations between electrode placements ($\approx 0.8$ for 20 min and about 0.9 for 24 h postmortem) were found for carcass impedance.

Skin, blood, organs, rumen, intestine, and abdominal fatty tissues are removed during slaughtering. These parts contribute to $\approx 50\%$ of live weight and have a considerable influence on the whole body impedance in vivo. For this reason, nonsignificant relationships (0.2–0.3) were found between in vivo and postmortem measurements at the same electrode placement. Stronger correlations (0.7–0.9) were observed between 20 min and 24 h postmortem measurements. This was expected, because no more manipulations on the carcass were made during this time. The water loss during chilling and the degradation of cell membranes postmortem, however, can differ between the carcasses and therefore influence the impedance values.

### 3.3. Partial correlations between impedance and carcass composition

The results are presented for the real parts at various frequencies (Tables 5 and 6). Other impedance variables showed no close relations to carcass composition and were not considered for further interpretation. A variation in empty live and carcass weight remained within the groups, despite being of the same final weight. For this reason, we calculated partial correlations with electrode distance and weight as covariates. The quotients $L^2/R_{40}$ and $L^2/R_{50}$ are not shown, because their correlations were almost equal to $R_{40}$ and $R_{50}$, respectively.

Very low correlations occurred at each time measured in MM-lambs at 35 kg. For the in vivo-measurements it is obvious that $R_0$ was stronger correlated to lean and fat content than $R_{\infty}$. However, we found the opposite result postmortem. The correlations for $R_{\infty}$ were greater than

#### Table 5
Partial correlations between impedance in vivo and carcass composition

<table>
<thead>
<tr>
<th>Variable</th>
<th>MM 35 kg</th>
<th>MM 45 kg</th>
<th>BM 35 kg</th>
<th>BM 45 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lean kg</td>
<td>Fat %</td>
<td>Lean kg</td>
<td>Fat %</td>
</tr>
<tr>
<td>Dorsal $R_0$</td>
<td>-0.26</td>
<td>-0.27</td>
<td>0.24</td>
<td>0.27</td>
</tr>
<tr>
<td>$R_{\infty}$</td>
<td>-0.24</td>
<td>-0.09</td>
<td>0.06</td>
<td>0.12</td>
</tr>
<tr>
<td>$R_{\infty}$</td>
<td>-0.28</td>
<td>-0.19</td>
<td>0.16</td>
<td>0.21</td>
</tr>
<tr>
<td>$R_{\infty}$</td>
<td>-0.31</td>
<td>-0.33*</td>
<td>0.26</td>
<td>0.29</td>
</tr>
</tbody>
</table>

| Ventral $R_0$ | -0.25 | -0.16 | 0.18 | 0.23 | -0.44** | -0.62*** | 0.58*** | 0.61*** | -0.16 | -0.38* | 0.36 | 0.32* | -0.14 | -0.47** | 0.54*** | 0.52*** |
| $R_{\infty}$ | -0.14 | -0.19 | 0.27 | 0.27 | -0.34 | -0.53*** | 0.54*** | 0.55*** | -0.12 | -0.28 | 0.23 | 0.21 | 0.05 | -0.32* | 0.55*** | 0.52*** |
| $R_{\infty}$ | -0.22 | -0.21 | 0.27 | 0.29 | -0.45* | -0.66*** | 0.65*** | 0.67*** | -0.15 | -0.35* | 0.31 | 0.28 | -0.03 | -0.47** | 0.66*** | 0.63*** |
| $R_{\infty}$ | -0.29 | -0.25 | 0.26 | 0.30 | -0.45* | 0.70*** | 0.69*** | 0.69*** | -0.12 | -0.34* | 0.31 | 0.27 | -0.07 | -0.48** | 0.63*** | 0.61*** |

MM, German Mutton Merino; BM, German Blackheaded Mutton; $R_{40}$, $R_{50}$, $R_{\infty}$ – real parts at direct current, infinite frequency, 50 kHz, and at the characteristic frequency.

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$. 
for $R_{\infty}$, but less than for $R_p$. $R_{50}$ was often stronger correlated to carcass composition than $R_{fc}$. This was especially evident at 24 h postmortem.

Although in vivo impedance measurements are more influenced by organs and guts, they sometimes correlated considerably better to lean and fat content than measurements on the carcasses. This contradicts the findings in beef and pigs by Marchello and Slanger (1994), Marchello, Berg, Swantek, and Tilton (1999b) and Swantek et al. (1992), who showed higher correlations for postmortem impedance measurements than in vivo ones. The results from various electrode placements differed between in vivo and postmortem measurements. In vivo, dorsal measurements showed higher correlations than ventral ones, apart from the MM-lambs at 45 kg. This can be explained by the lower length of the needles or the greater part of rumen and intestines, monitored by the ventral electrodes. Postmortem, the ventral measurements were better correlated to carcass composition, except for MM-lambs at 35 kg.

Because of the close relationship between the absolute and relative carcass composition in lambs of similar weight, the correlations of the impedance to the absolute tissue masses and the relative tissue contents are similar in most cases.

### 3.4. Prediction of carcass composition by regression equations

Tables 7–9 report the results for the prediction of absolute and fractional lean within breeds and weight groups and for the total material. $R^2$ and root mean square error (RMSE) for the model as well as the partial $R^2$ of the significant variables after stepwise regression are shown. For a better comparability, RMSE is presented relative to the standard deviation of lean mass and lean percentage, respectively. Body weight was often significant for the estimation of lean mass within the groups, although its variation was only small. Besides the weight, the impedance at higher frequencies was often significant for carcass composition while a significance for $R_p$ was found only in three cases. For the prediction of lean percentage, the empty live weight was not significant, the hot or chilled carcass weight was only significant for the estimation of lean mass within the groups. Among the impedance parameters, the real parts at higher frequencies were preferably included in the equations.

For the total material, the weight alone had a high impact for the prediction of lean mass. Equations including only the body weight showed root mean square errors between 0.38 and 0.44 (data not shown). Besides
the weight, several impedance parameters were significant, mainly at higher frequencies. $R^2$ increased and RMSE decreased due to inclusion of impedance in the equation. The body weight was also significant for the prediction of lean %, however, with a lower partial $R^2$ than for estimation of the lean mass. Additional to the
weight, $R_{50}$ and $R_{fc}$ were significant. In contrast to our study, Berg, Neary, Forrest, Thomas, and Kaufmann (1996) found a higher accuracy for lean percentage using the in vivo-impedance at 50 kHz and the live weight ($R^2 = 0.55$, RMSE = 0.69).

The lean mass was predicted with considerably higher precision in the total material than in lambs of similar weight. This is mainly due to the high correlations between weight and lean mass. The same was found for the fat mass (data not shown). However, the carcass grading system in Europe is based on fractional carcass composition. Lean and fat percentage can only be inaccurately estimated in lambs of similar weight as well as in the total material. A RMSE of $\approx 0.80$ is relatively high. Other methods, like Magnetic Resonance Tomography gives values of about 0.30 (Streitz, Baulain, & Kallweit, 1995). The lower precision for the predicted fractional carcass composition was confirmed by Berg et al. (1996, 1997) and Kraetzl, Thiele, Tomaczak, and Kamphues (1995).

Alternately, lean % or fat % could be calculated by using the estimated mass of lean or fat. However, the $R^2$-values had the same low values compared with the direct estimation by regression equations (data not shown) and is therefore not favourable.

### 4. Implications

The high accuracy for the prediction of lean and fat mass is mainly based on the inclusion of live or carcass weight in the regression equations. The impedance contribution to accuracy is relatively small. However, the carcass evaluation is based on lean or fat percentage. This can be estimated by impedance only with low precision, even if the weight is included. The accuracy for the fractional carcass composition within breed and weight groups did not differ substantially from the total material. We conclude that the impedance method is not suitable for the prediction of carcass composition, neither in lambs of similar weight nor in heterogeneous animals.

### References


