Factors affecting the electrical impedance of growing-finishing pigs

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Matte, J.J., Robert, S., Godcharles, L., Bertin-Mahieux, J. and Martineau, G.P. 1992. Factors affecting the electrical impedance of growing-finishing pigs. Can. Agric. Eng. 34:189-194. In a first trial, 12 pigs between the ages of 9 and 22 weeks were used in a 2 x 2 factorial design to measure the effect of 2 levels of 60 Hz ac voltage (2 and 5 V) and 2 flooring conditions (woven wire covered with water (WW) or dry (WD)) on total body impedance (TBI). Whatever the age of the animal or the flooring conditions, the overall TBI was higher (P < 0.003) at 2 V than at 5 V (1300 vs 1091 Ohm). The effect of age on TBI was dependent upon the wetness of the floor (P < 0.01). At 10 weeks of age, TBI was higher on WD than on WW (3041 vs 1031 Ohm) while the corresponding difference, at 18 weeks of age, was less pronounced (1036 vs 778 Ohm). From 18 to 22 weeks, the decrease of TBI persisted on both flooring conditions but was more marked on WW (17%) than on WD (7%). This reduction in TBI with age could be explained by the increase of the contact area and of the pressure exerted by hooves on the floor, which are major factors influencing the quality of floor-hooves contact. In a second trial, two 15 week-old pigs were used in a factorial arrangement of treatments (2 x 3 x 4) to measure the effects of voltage (1 and 2 V), current frequency (60, 1000, 3000 and 10,000 Hz) and flooring surfaces (WW, WD and a copper plate covered with water, (CW)) on TBI. No difference (P > 0.38) could be measured between the 1 V and the 2 V treatments. Whatever the voltage, the overall value of TBI at 60 Hz on CW was lower (P < 0.01) than on WD but similar to that measured on WW. However, as current frequency increased, the differences among surfaces disappeared (P > 0.05). These results indicate that a greater amount of current could pass through the body of growing-finishing pigs as they get older and/or heavier. Among the studied factors affecting TBI, wetness of the floor and current frequency appeared to be the most important.

Key words: Stray voltage, impedance, floor, wetness, current frequency, age, growing-finishing pigs.

Lors d’un premier essai, 12 porcs ont été répartis à l’intérieur de traitements factoriels 2 x 2 afin de mesurer l’effet de deux niveaux de voltage ac 60 Hz (2 et 5 V) et de deux conditions de planchers (treillis métallique recouvert d’eau et sec) sur l’évolution de l’impédance corporelle totale entre l’âge de 9 et 22 semaines. Quelque soit l’âge de l’animal ou les conditions du plancher, l’impédance corporelle totale était plus élevée à 2 V qu’à 5 V (P < 0.003), les moyennes globales se situant respectivement à 1300 et 1091 Ohm. L’effet des conditions du plancher était différent selon l’âge du porc (P < 0.01). En effet, à l’âge de 10 semaines, l’impédance corporelle totale était de 3041 Ohm sur plancher sec comparativement à 1031 Ohm sur plancher mouillé alors que la différence correspondante à 18 semaines était moins prononcée, soit 1036 vs 778 Ohm. Par la suite, entre l’âge de 18 et 22 semaines, la diminution d’impédance corporelle totale a persisté mais elle était alors plus marquée sur plancher mouillé (17%) que sur plancher sec (7%). Cette diminution de l’impédance corporelle totale avec l’âge de l’animal a été associée à un accroissement de la pression exercée par les ongles sur le plancher, un facteur déterminant de la qualité du contact entre les ongles et le plancher. Lors d’un deuxième essai, des traitements factoriels 2 x 3 x 4 ont servi à mesurer l’effet du voltage (1 et 2 V), de la fréquence (60, 1000, 3000 et 10000 Hz) et du type de plancher (treillis métallique sec, treillis métallique et plaque de cuivre recouverts d’eau) sur l’impédance corporelle totale de deux porcs âgés de 15 semaines. Aucun effet de voltage (P > 0,38) n’a été observé. Quelque soit le voltage, l’impédance corporelle totale à 60 Hz était plus élevée (P < 0,01) sur la surface de cuivre recouverte d’eau que sur le treillis métallique sec mais similaire à celle mesurée sur le treillis métallique recouvert d’eau. Cependant, cette différence entre planchers disparaissait avec l’augmentation de la fréquence (P < 0,05). Ces résultats indiquent donc que la quantité de courant qui traverse le corps de l’animal s’accroît avec l’âge et le poids. L’état d’humidité du plancher et la fréquence du courant sont également des facteurs importants influant l’impédance corporelle totale du porc.

Mots-clés: Tensions parasites, impédance, plancher, humidité, fréquence, âge, porc d’abattage.

INTRODUCTION

Scientific knowledge on the effects of stray voltage in swine is limited. The two scientific reports published so far show that in spite of some modifications in drinking and feeding patterns and a slight decrease in feed intake, levels of voltage in the range of 2 to 5 V could not affect growth performance, health or aggression against penmates (Gustafson et al. 1986; Robert et al. 1991). Such results contrast with the severe detrimental effects of stray voltage on animal health and production often reported in the field. Therefore, basic information on the electrical impedance properties of the body is essential for a better understanding of the stray voltage problem (Hultgren 1990). Indeed, for a given voltage level, the current circulating between two contact points of the animal’s body is determined by the total body impedance. In humans, the total body impedance (TBI) is composed of the internal body impedance which is mainly resistive (Biegelmeier 1985) and of two skin impedances at the contact points (e.g., between hands) that are both capacitive and resistive (Smoot and Mogan 1985). In this last case, the impedance at the contact points depends on factors such as surface wetness, type of electrode used for measurements, current frequency, voltage level and quality of contact (Biegelmeier 1985). In swine, the most common body pathway of electrical current is likely to occur between the mouth and the hooves, when the animals are eating or drinking.
(Gustafson et al. 1986; Hultgren 1990). In modern intensive housing environments, the TBI of a pig would be composed of three parts: the internal body impedance (including mucosa and keratinized tissues), the impedance of the contact between the mouth and the feeder or the drinker and the impedance of the contact between the hooves and the floor. As is the case for cows (Hultgren 1990), the factors influencing the impedance at the contact points are likely to be similar to those identified in humans but the respective importance of each of these factors has never been specifically studied in swine.

Although the factors influencing impedance are not known in swine, some values collected in specific situations have been reported. For example, in sows, the only value available (360 Ω) was measured between one copper plate placed under the sow’s belly and another one wedged between the sow’s snout and a watering cup (Stetson et al. 1981). Regarding the internal body impedance, Prieto et al. (1985) reported values around 200 Ω for pigs of mass between 60 and 90 kg. In growing-finishing pigs, the mouth-to-hooves impedance has been estimated to be between 500 and 1000 Ω with large variations among animals (Gustafson et al. 1986; Appleman et al. 1985; Hultgren 1990); such variations are probably related to the factors influencing TBI.

Results from a recent experiment on stray voltage (Robert et al. 1991) suggested that TBI in growing-finishing pigs might be age-dependent. The present experiment therefore was undertaken to evaluate the effect of age on total body impedance of growing-finishing pigs during the fattening period. The importance of other factors such as voltage level, current frequency, wetness conditions of the floor and flooring material were also investigated.

MATERIAL AND METHODS

Equipment and preliminary trials

A special restraining cage was built for this experiment. The anterior part and the sides of the cage were adjustable in order to accommodate animals of body mass between 20 and 120 kg. The floor was insulated from the rest of the cage and the support structure allowed the type of floor to be changed.

The electrical circuit used is illustrated in Fig. 1. The first contact with the animal was established between the hooves and the metallic slatted floor ("Woven wire") and the second, between the left side of the cheek and a non-traumatic clamp inserted at the angle of the lips. The synthesizer/function generator (Model 171, Wavetek, San Diego, CA) produced the required sinewave voltage which was applied between the non-traumatic clamp and the metallic floor insulated from its support structure. The voltage was measured by a digital voltmeter (Model 3030, Beckman, Montréal, PQ) and the current, by a digital ammeter (Model Industrial 300, Beckman, Montréal, PQ). The resistor had a value of 1000 Ω and was used to check the circuit and to predetermine the voltage. The switch was used to apply the voltage to the pig (position 1) or to the resistor (position 2).

Two preliminary trials were conducted to verify the quality of the contacts at the mouth and the hoof levels. The first trial was carried out to evaluate the effect of age on the surface occupied by a hoof on the floor. Two pigs were used between the ages of 10 to 14 weeks and two others, between the ages of 16 to 22 weeks. Hoof prints (anterior right leg) were taken in a modeling clay and surface of contact was measured with a planimeter (Model Planix-2, Tamaya Digital Planimeter, Tokyo, Japan). These values were used to calculate the pressure exerted by the hoof on the floor (bodyweight divided by surface area of the hoof print).

The second preliminary trial was conducted to verify if the area of the contact with the cheek influenced TBI. The surfaces of the clamp alone (80 mm²) or fixed with two different steel plates (surfaces of 625 mm² and 1250 mm²) were compared. Since no differences in TBI were noted between the three clamp surfaces, all further measurements were carried out with the clamp alone.

Trial 1

A group of twelve pigs averaging 9 weeks of age was divided into 6 pairs of one barrow and one gilt (average mass ± SE, 20.5 ± 0.3 kg). Each pair was placed in one pen (1.8 m x 3.6 m) on a concrete floor. They were fed ad libitum throughout the experimental period. During the growing (9 to 15 weeks) and the finishing periods (15 to 22 weeks) they received a commercial diet containing respectively at each period, 14.0 and 14.0 MJ per kg of digestible energy, 16% and 14% of protein, 0.8% and 0.7% of lysine, 3% and 3% of fat, 5% and 5% of fiber, 0.75% and 0.70% of Ca and 0.60% and 0.60% of P. Animals were cared for according to the recommended code of practice of Agriculture Canada (1984).

The treatments were imposed on all animals according to a factorial arrangement (2 x 2) once every two weeks from 10 to 22 weeks of age. Two voltage levels (2 and 5 V of continuous sinusoidal ac voltage, 60 Hz) were used with two flooring conditions, woven wire either dry (WD) or covered with water (WW) for each animal. Verification was made to ensure that there was no residual effect on current measurements due to the succession of treatments within the same animal. For each animal and each treatment, five stable readings of the current circulating in the circuit were collected at 10 s intervals from the ammeter. The mean value of these readings was used to calculate TBI. Each pig was weighed on...
the day preceding the impedance test.

**Trial 2**

Two pigs from the group described in Trial 1 were randomly chosen and submitted, under different conditions, to body impedance measurements at 15 weeks of age (body mass of 55 and 58 kg). A factorial arrangement of treatments (2 x 4 x 3) was used to measure the effect of two voltage levels (1 and 2 V) in combination with four levels of current frequency (60, 1000, 3000 and 10,000 Hz) and three types of floor (WD, WW and a copper plate covered with water, CW) on TBI.

The levels of voltage were lower than those used in Trial 1 since a combination of 5 V, high frequencies and use of a highly conductive material as flooring surface (copper plate covered with water) created excessive discomfort to the animals. The copper plate covered with water was chosen in order to give an indication of the impedance of the animal when the quality of contact between the hooves and the floor surface was maximized. Measurements, equipment and husbandry practices were similar to those described in Trial 1. Five readings of the current circulating in the circuit were also collected for each treatment and each animal but the power was cut for 10 s between each reading. Such procedures eliminated the risk of residual effect of the previous treatment, especially with measurements at high frequencies.

**Statistical analysis.**

Data were analysed using the General Linear Models procedure of SAS (1985). In both trials, a split-split-plot model was used. Each block represented measurements for all treatments collected on one animal. In Trial 1, the variation of TBI with age was compared according to the conditions of the flooring surface and to the voltage levels. The conditions (WD or WW) of the flooring surface were the main plots, the voltage levels (2 and 5 V) were the sub-plots and the different ages of pigs (10, 12, 14, 16, 18, 20 and 22 weeks) were the sub-sub-plots. In Trial 2, the variation of TBI with frequency was compared according to flooring surfaces and to voltage levels. The flooring surfaces (WD, WW and CW) were the main plots, the voltage levels (1 and 2 V) were the sub-plots and the current frequencies (60, 1000, 3000 and 10,000) were the sub-sub-plots. In Trial 2, the following *a priori* comparisons were made: CW vs WD and CW vs WW. In all cases, least square means were compared using the orthogonal contrasts for quantitative treatments. Repeated measurements on TBI according to age or frequency were partitioned according to Rowell and Walters (1976).

**RESULTS**

**Trial 1**

No health problems were observed during the experimental period. As presented in Fig. 2, TBI was higher (P < 0.003) at 2 V (mean ± SEM = 1300 ± 60 Ω) than at 5 V (1091 ± 52 Ω). The effect of age on TBI was dependent upon the wetness of the floor (P ≤ 0.01). Whatever the voltage, overall TBI was 3041 ± 269 Ω on WD and 1031 ± 36 Ω on WW at 10 weeks of age while the corresponding values, at 18 weeks of age, were 1036 ± 36 Ω and 778 ± 23 Ω. Such values represent a decrease of 66% on WD and 25% on WW from 10 to 18 weeks of age. Thereafter, the decrease in TBI persisted on both flooring conditions but was more pronounced on WW than on WD; values at 22 weeks of age averaged 644 ± 21 Ω on WW and 959 ± 41 Ω on WD. The body mass recorded from 10 to 22 weeks of age and the corresponding pressure exerted by a hoof on the floor are presented in Table I. The pressure exerted by the hoof on the flooring surface increased by 67% between 10 and 18 weeks of age and tended to remain constant thereafter (increase of approximately 3%).

<table>
<thead>
<tr>
<th>Age (weeks)</th>
<th>Body mass¹ (kg)</th>
<th>Pressure exerted by a hoof on floor² (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>23.6 ± 0.5</td>
<td>265</td>
</tr>
<tr>
<td>12</td>
<td>32.3 ± 0.7</td>
<td>314</td>
</tr>
<tr>
<td>14</td>
<td>44.7 ± 1.3</td>
<td>392</td>
</tr>
<tr>
<td>16</td>
<td>56.5 ± 1.6</td>
<td>402</td>
</tr>
<tr>
<td>18</td>
<td>69.8 ± 1.7</td>
<td>442</td>
</tr>
<tr>
<td>20</td>
<td>85.5 ± 2.4</td>
<td>451</td>
</tr>
<tr>
<td>22</td>
<td>100.6 ± 2.7</td>
<td>451</td>
</tr>
</tbody>
</table>

¹ Values are means ± SEM.  
² Values are means of two pigs. However, the animals used for measurements at 10 to 14 weeks were different from those used at 16 to 22 weeks of age.

**Trial 2**

No difference (P ≥ 0.38) in TBI could be measured between the 1 V and the 2 V treatments. The TBI of pigs decreased quadratically (P < 0.05) with increasing current frequency, the overall means (± SEM) varying from 1163 ± 166 Ω at 60 Hz to 302 ± 12 Ω at 10,000 Hz (Table II). Whatever the voltage or the current frequency used, the average TBI on CW (456 ± 56 Ω) was lower (P < 0.01) than on WD (867 ± 161 Ω), but was similar to that measured on WW (567 ± 69 Ω). However, as current frequency increased, the differences among surfaces disappeared as shown by the interaction between flooring surface conditions and the linear effect of frequencies (P ≤ 0.05) (Table II).

**DISCUSSION**

**Trial 1**

Although only two levels of voltage were used in the present trial, it appears that TBI decreases with increasing voltage up to 5 V. Similar observations have been reported, in humans, for voltage levels varying from 5 to 1000 V at 50 Hz (Biegelmeier 1985) and 60 Hz (Nute 1985). In these two studies, data below 40 V were collected on live subjects while those over 40 V were extrapolated from values obtained with corpses (Biegelmeier 1985). In humans, the TBI decrease with increasing voltage is due mainly to skin impedance variations since the internal body impedance for a given subject under given conditions does not vary with voltage (Smoot and Mogan 1985). However, for voltages over 50
Table II: Changes in total body impedance (Ω) with frequency and voltage according to wetness and nature of the floor (Trial 2)\(^1,2\)

<table>
<thead>
<tr>
<th>Current frequency (Hz)</th>
<th>Voltage (V)</th>
<th>Flooring surface</th>
<th>Wet copper</th>
<th>Wet woven wire</th>
<th>Dry woven wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1</td>
<td>824±120</td>
<td>1069±157</td>
<td>2041±775</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>779±96</td>
<td>893±98</td>
<td>1373±5</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1</td>
<td>428±11</td>
<td>567±78</td>
<td>986±210</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>428±15</td>
<td>544±21</td>
<td>781±95</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>1</td>
<td>346±42</td>
<td>422±37</td>
<td>599±124</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>320±12</td>
<td>409±7</td>
<td>501±65</td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>1</td>
<td>278±25</td>
<td>321±0</td>
<td>350±52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>248±3</td>
<td>311±2</td>
<td>303±7</td>
<td></td>
</tr>
</tbody>
</table>

1 Values are means ± SEM.
2 Interaction surface * linear effect of frequencies (P ≤ 0.05) (See text for explanation).

100 V the skin impedance becomes negligible because of tissue breakdown (Biegelmeier 1985). In swine, Prieto et al. (1985), using anesthetized animals to simulate the effect of voltage on human body impedance, found a value of about 200 Ω at 100 V which is likely to be a valid evaluation of the internal body impedance of growing-finishing pigs. Therefore, most of the variation of TBI reported in the present trial would not be due to the internal body impedance.

Even if it did not vary with the level of voltage and did not represent a large part of the TBI, the internal body impedance could be age-dependent. The drastic changes of body composition that occur in pigs from 10 to 22 weeks of age (Walstra 1980) might contribute to the age effect observed on TBI of pigs. In fact, body impedance is used as an indicator of body composition in humans (Cohn 1985; Khaled et al. 1988) and rats (Hall et al. 1989).

Other factors such as the quality of contact at mouth and hoof levels and the intrinsic impedance of these tissues might be involved in the variation of the TBI. Under the present experimental conditions, variations at the mouth level were minimal due to uniform use of equipment and device throughout the experimental period. However, moistness of the floor, at the level of the hoof, improved the quality of contact as was previously observed (Hultgren 1990). The present results indicate that this effect was more pronounced in young pigs (10 and 12 weeks old). On the dry floor, the quality of contact seemed to be linked to the pressure exerted by the hoof on the flooring surface. Even if, due to the experimental design, no correlation could be calculated between the variation in TBI and that of hoof pressure on the dry woven wire, the results presented in Table I and Fig. 2 suggest an inverse relationship between the two factors. In fact, the plateau of hoof pressure observed in the present experiment from 18 to 22 weeks of age is in agreement with results reported by Webb (1984) showing that hoof pressure at these ages is almost independent of the weight of the pig.

With regard to flooring conditions, our results suggest that the influence of hoof pressure on TBI might be considerably reduced on a wet floor as compared to a dry floor. In this way, the contribution of the contact impedance between foot and floor to the variation of TBI with age seems to be more important on a dry floor than on a wet floor.

The degree of individual variation in TBI values among animals also seemed dependent upon treatments. Indeed, SEM values were about 5 times higher on dry woven wire as compared to wet woven wire. Such an effect could be related to a better and more uniform quality of contact between the hooves and the floor on a wet surface as compared to a dry surface.

**Trial 2**

At the present time, information on the effects of current frequency on TBI is limited. As reviewed by Rémond (1986), most of the studies reported results at levels of frequency below 100 Hz, mainly at 50 and 60 Hz. The present trial aimed to document, in swine, estimates of the TBI at levels up to 10,000 Hz since they are superimposed to the 60 Hz frequency when adjoining equipment uses rectifiers or when transient voltages are present due to switching of leads. In humans, the skin impedance, which is mainly capacitive,
decreases when current frequency increases (Biegelmeier 1985). If the capacitance properties of skin and hooves in pigs are similar to those of human skin, it could explain that the TBI of our animals decreased as the current frequency increased.

At 60 Hz, the difference in TBI between dry and wet floors is probably due, as shown in Trial 1, to the quality of contact at hoof level. However, at 10,000 Hz, voltage and flooring surface became negligible factors on TBI variation. At such a level of frequency, the TBI observed is around 300 Ω, which is likely to be close to the internal body impedance of pigs (Prieto et al. 1985). In humans, the decrease of TBI observed with increases of frequency has been associated with tissue or skin breakdown (Biegelmeier 1985). Since no signs of skin damage were noted in the present experiment, the decrease of TBI with the increasing level of frequency might be due to a substantial decrease with frequency in the impedance of the capacitive component of the skin and hooves.

The absence of voltage effect on TBI seen in Trial 2 contrasted with the response observed in Trial 1. Three factors could explain this discrepancy. Firstly, the number of animals (replications) in Trial 2 (n = 2) was much smaller than in Trial 1 (n = 12); variations between replications may have prevented the appearance of a significant effect. Secondly, the intervals between levels of voltage studied were different, 3 V in Trial 1 as compared to 1 V in Trial 2; the expected difference between treatments therefore could be small enough to be not significant. Finally, the effect of current frequency could have masked an effect of voltage since TBI values tended to reach a plateau at high frequencies whatever the voltage level. Therefore, results reported in Trial 1 are probably more representative of the general effect of voltage on TBI in growing-finishing pigs.

CONCLUSION

The results of the present experiment confirm the hypothesis raised in a previous experiment (Robert et al. 1991) suggesting that TBI, in growing-finishing pigs, is age or weight-dependent. On a dry surface, this effect would be due to an improved quality of contact, a consequence of an increased pressure of hooves on the flooring surface. Among the other factors involved in the variation of TBI, wetness of the floor and current frequency appeared to be the most important. The effects of voltage and current frequency on body impedance suggested that skin and hooves have impedance properties comparable to that of human skin.

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Fig. 2. Variation with age of pigs of the total body impedance according to voltage and wetness of the floor. Pooled SEM of the 12 pigs were 21, 106, 19 and 89 for the treatments 2 V-wet woven wire, 2 V-dry woven wire, 5 V-wet woven wire and 5 V-dry woven wire, respectively.


