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**Animal based welfare measures and
their correspondence with parameters of
head-only electrical stunning in pigs**

Summary of PhD thesis

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1. Introduction

Three main concepts of animal welfare are existing from scientific viewpoints: physical, mental and natural approaches. Due to different concepts, measurement of animal welfare is not uniform, because aspects are different too. Welfare can be evaluated well, if environmental and animal based measures are interpreted together.

Specific location of checking animal welfare is slaughterhouse, where animals are stunned before bloodletting. The aim of stunning is to render animals unconscious and painless until death. This state can be checked best via animal based signs. One purpose of the current study was to choose and use those animal based measures from the toolbox of welfare indicators, which are feasible, sensitive and specific in the practice. This was the prerequisite for determining technical parameters of stunning.

Parameters of head-only electrical stunning was investigated by some researchers. Based on their results, 1099/2009/EC Council Regulation in effect requires 1.3 A for head-only electrical stun of pigs. Nevertheless, European Food Safety Authority says that this technical reference data is either rather old or worked out

under experimental laboratory conditions, consequently there is a need to verify this data under commercial conditions.

Another purpose of the current study was to investigate correspondence between current and effective stunning as well as determining minimum required current for effective stun. Having regard that other factors (e.g. duration of load, frequency, electric work) may influence efficiency of stuns, effect of these parameters on stunning was studied too.

So as to perform measurements, special devices has been developed, that set and displayed technical parameters (current, voltage, frequency).

2. Material and method

Goal of Trial 1 was to verify correspondence between technical parameters of head-only electrical stunning of pigs (i.e. environmental circumstances) and efficiency of stunning (i.e. animal based signs) under commercial conditions. At first place, effect of current was examined, next to this duration of load and impedance of head too. Goal of Trial 2 and 3 was to establish those physical parameters which describe well the effectiveness of stunning. In Trial 2, frequency needed for proper stunning was determined, whereas in Trial 3, the effect of current, electric work and stun-to-stick period was investigated.

2.1. Trial 1

Measures were carried out at 4 different, Hungarian slaughterhouses (at least on two different days in each) during their everyday practice. No changes were required compared to routine work either in habits of slaughter men, in settings of stunning equipment (voltage, frequency, and wave-form). Head of pigs were watered before stunning; tongs were positioned between the eyes and the base of ears. Those cases, where positioning was different from this and the current flow did not span the brain, were excluded from this study. Altogether 145 pigs were part of evaluation.

In each case following data were recorded by reading displays of measuring devices or by visual examination: individual live weight (kg), current (A) and voltage (V) during stunning, duration of load (s), effectiveness of stunning, grading of meat (SEUROP). Current and voltage were measured with an analogue instrument developed individually for the purpose. The instrument included two ampere-meters (scope: 0-1 and 0-5 Amps) and one voltage-meter (scope 0-300 Volts). This device was placed in the circuit as follows: it was clipped to the original tongs in serial connection and another tong connected to the device was used to stun pigs by slaughter man. Duration of load was quantified by a simple stopwatch. Effectiveness of stunning was established on animal based signs as follows:

1. immediate collapse,
2. immediate onset of tonic seizure lasting several seconds followed by clonic seizure,
3. apnoea,
4. upward rotation of eyes,
5. absence of response to nose prick (checked with a knife available for cutting blood vessels).

Recognizing at least four criteria out of these five was regarded as effective stunning.

Recorded data were statistically analyzed.

The level of significance was set at $P \leq 0.05$.

2.2. Trial 2

Measurements were performed in one abattoir, on 6 different days, on 193 pigs, in routine slaughter conditions for studying the effect electrical frequency used for head-only electrical stunning. Animals were stunned and slaughtered under commercial slaughterhouse operations for human consumption, i.e. no experimental conditions were used. The slaughterhouse used head-only electrical stunning. The head of pigs was watered before stunning. Pigs were fixed in a stunning pen. Tongs were positioned between the eyes and the base of the ears in order to achieve proper flow of current in the brain. Each individual stunned on the day of examination was included in the study. Those cases, where positioning was incorrect, were excluded from the study as only correctly positioned tongs can provide an uninterrupted flow of electric current through the brain.

Stunning was carried out with an equipment specially designed and produced for the studies by a factory specialized for slaughterhouse facilities. The equipment operates with line power. Incoming current is transformed and rectified, which results in a DC with intensity outcome ranging from 20 to 2000 mA. Stunning current intensity can be set with a potentiometer. The equipment modulates the current with impulses, of which

frequency can be set in 3 stages: 150 Hz, 300 Hz, 2000 Hz, respectively. The equipment is supplemented with an ampere- and a voltage meter, and it displays current intensity and voltage in an easily readable manner. The duration of load and the stun-to-stick period were measured by a stopwatch.

The data of a total of 193 fattening pigs were analyzed. The frequency of stunning current was set as follows: in 159 and 34 cases to 150 Hz and 300 Hz, respectively. At 2000 Hz, stuns were found inefficient, therefore no pigs were stunned at this Hz considering that pigs were stunned and slaughtered for commerce and not for experiment.

The following data were recorded in all cases: current frequency (Hz) current intensity (A) and voltage (V), duration of load, and stun-to-stick period.

The effectiveness of stunning was monitored at three points:

1. immediately after stunning,
2. before the moment of sticking, and
3. after sticking, during bleeding.

In order to assess the pigs' state, animal-based measurements were carried out at each monitoring point. Based on internal medicine diagnostic tools and the toolbox the following measurements were carried out.

Measurements immediately after stunning:

1. Examination of breathing: proper electrical stunning of pigs shall result in the immediate onset of apnoea, which could be checked by observation.
2. Observation of posture: a proper stunning shall result in the immediate collapse of the animal, which could be checked by observation.
3. Examination of motor activity: electrical stimuli cause motor excitement, which could be observed by the onset of tonic-clonic seizures.
4. Examination of vocalization: any vocalization was regarded as a sign of consciousness.
5. Examination of the eyes: depressed excitability of the oculomotor nerve is indicated by pointedly fixed eyeballs or by eyeballs showing upward rotation, which could be observed.

Altogether 5 criteria described above were examined. For the evaluation of consciousness a scoring system was used, where score 1 represented proper unconsciousness and score 0 denoted superficial or improper unconsciousness. Stunning was regarded effective on *adequate* level if all five criteria were scored 1. Cases were regarded effective on *acceptable* level, where at least four of the five criteria were met and scored 1.

Consequently, evaluation was carried out on two levels: *adequate* and *acceptable* levels. Stuns under these levels were regarded *non-adequate* and *non-acceptable*.

Measurements before and after sticking were focused on signs indicating the recovery of consciousness and nociception as follows.

1. Examination of breathing: return of rhythmic breathing could be observed if 3–4 breaths or gags occur at same time intervals.
2. Examination of posture: if hoisted and shackled pigs tried arching the neck or body, this was regarded as an attempt to regain posture.
3. Examination of motor activity: observation and palpation of the ear could reveal stiffness, which occurred when muscle tone was being regained.
4. Examination of nociception/analgesia: any response to nose pricking or ear pinching could be regarded as a sign of recovery of nociception, which was tested with a knife. After sticking, involuntary urination and defecation could also be observed.
5. Examination of vocalization: any vocalization was regarded as a sign of consciousness.

6. Examination of the eyes: automatic blinking or blinking provoked by touching the cornea or the eyelid was regarded as sign of recovery.

Under practical conditions the above 6 criteria could be examined before and after sticking. Using the above-described scoring system unconsciousness/analgesia was regarded effective on *adequate* level if all criteria were scored 1 (total score: 6). From the practical point of view, effectiveness of unconsciousness on *acceptable* level was also established. In this case at least 5 of the 6 criteria were scored 1. Stuns under these levels were regarded *non-adequate* or *non-acceptable*.

Data collected and recorded from each individual pig were analyzed statistically. After descriptive statistics, the effect of the given parameter on stunning and maintenance of unconsciousness on *adequate* and *acceptable* level was analyzed by logistic regression. The level of significance was set at $P = 0.05$.

2.3. Trial 3

The measurements were carried out at 3 Hungarian slaughterhouses on 9 different occasions under routine work conditions. Animals were stunned and slaughtered under commercial slaughterhouse operations for human consumption, i.e. no experimental conditions were used. Each slaughterhouse

used head-only electrical stunning. The head of pigs was watered before stunning. Pigs were fixed in a stunning pen. Tongs were positioned between the eyes and the base of the ears in order to achieve proper flow of current in the brain. Each individual stun on the day of examination was included in the study. Those cases, where positioning was incorrect, were excluded from the study as only correctly positioned tongs can provide an uninterrupted flow of electric current through the brain

Stunning device was identical with the one described in Point 2.2.

The data of a total of 405 fattening pigs were analyzed. During stuns two parameters were changed: current intensity and the duration of stunning. Frequency was set at 150 Hz. Data were collected in two experiments as follows.

1. In the first experiment we examined if duration of stunning had any effect on the effectiveness of stunning. For this reason measurements were carried out at two different slaughterhouses on four different days. At slaughterhouses **A** and **C** 65 and 75 pigs, respectively, were included in this examination. At slaughterhouse **A** duration of stunning had been randomized in advance by a numerical generator (from 3 to 18 sec with 3-sec intervals) and the slaughter man was asked to perform

the stunning accordingly. Current was set according to the slaughterhouse experience (average 0.77 A), voltage was measured between 145 and 360 (average 230 V). At slaughterhouse **C** the slaughter man was asked to stun according to his own experience, which ranged 15 to 35 seconds. Current was set according to the slaughterhouse experience (average 0.96 A), voltage was measured between 110 and 250 (average 161 V).

The stun-to-stick period was an additional variable. This is the period that lasts from the end of stunning, through shackling and hoisting the pigs, to the moment of sticking. The routine operation was observed in slaughterhouse **A**, where this parameter varied depending on the number of available slaughter men and the efficiency of their work. This variable was recorded in five different days, on a total of 159 pigs. The stun-to-stick period varied between 32 and 85 sec.

Fulltime covers the time period from the beginning of stunning till sticking, of which data were collected and processed too in slaughterhouse A.

2. In the second experiment the effect of current intensity was examined. In this case the measurements took place

at two slaughterhouses (**A** and **B**) on 8 different days. Data of 296 pigs were collected at the two slaughterhouses. Current intensity was changed randomly by setting the potentiometer on the stunning equipment. Current intensity was between 0.35 and 2.57 A. As for electric work, values between 358 and 10,036 Wattsecundum (= Joule) were calculated. Duration of stunning was set by slaughter man, it varied between 3 and 28 secs with average of 13 secs.

The following data were recorded in both experiments in all cases: current intensity (A), voltage (V), duration of load, and stun-to-stick period. Electric work was calculated from the recorded data ($W=U \times I \times t$, where W =work, U =voltage, I =current, t =time).

The effectiveness of stunning was monitored at three points:

1. immediately after stunning,
2. before the moment of sticking, and
3. after sticking, during bleeding.

In case of stun-to-stick and fulltime, only second and third monitoring point were used.

Animal based measurements were carried out as described in Point 2.2.

Data collected and recorded from each individual pig were analyzed statistically. As examinations were carried out at more than one slaughterhouse, the data collected at each location were analyzed separately. Then the data were pooled and evaluated to see if location had statistically valid effect on the result. After descriptive statistics, the effect of the given parameter on stunning and maintenance of unconsciousness was analyzed on *proper* and *acceptable* levels by logistic regression. The level of significance was set at $P = 0.05$. Where it was possible, minimum required values were established for different variables with different accuracies.

3. Results

3.1. Trial 1

145 pigs were involved in the evaluation. Altogether 88.3% of stunning was effective (128 cases out of 145). Recorded current data ranged from 0.14 to 5 Amps. The effectiveness of stunning was studied at two limit values (1.3 A, 0.4 A, respectively). Using 1.3 A no significant difference were found at slaughterhouse **1**, **2** and **3**. Contrary, at slaughterhouse 4 the effectiveness over 1.3 A was significantly better ($P=0.01$). Since out of the results of measured current values under 0.4 A were obtained only in slaughterhouse **3**, this threshold could be examined only here.

However, the result of Fisher's Exact test showed no significant difference at Slaughterhouse 3.

Out of parameters expected to influence effectiveness (current, voltage, duration of load) only current showed significant effect using binomial regression ($P=0,013$). The effect of other units including current such as electric power ($I \times U$) or energy ($I \times U \times t$, where t =duration in seconds) on effectiveness was significant too. Since no significant interaction could be found between location and those parameters (current, wattage, energy) which are significant to effectiveness, difference between locations was a constant parameter (voltage) and the duration of load determined by slaughter man. A minimum current with 95% accuracy could be determined by location (0.69 A, 3.12 A, 2.16 A, 4.78 A, respectively).

Individual live weight of pigs took part in the evaluation ranged from 30 to 150 kilos, but the majority of pigs (115 animals) were over 100 kilos. Nevertheless, impedance of head was varying from 32 to 571.43 ohm (median 159.56 ohm). Correlation of individual live weight and impedance of head could not be established.

Meat grading was carried out only on finishing fatteners (133 individuals), carcasses were categorized into S, E, U and R

classes, and none of them was classed into O and P. Evaluating connection between meat grading and impedance of head showed no significance by Kruskal-Wallis-rank-sum test.

In case of duration, recorded values ranged from 4 to 25 seconds (median 12,9 seconds). Since duration of load showed no significant effect on effectiveness of stunning, determination of duration was investigated in correlation to different parameters. Duration at different locations was significantly different but no reliable dependence thereof on other parameters could be proved.

3.2. Trial 2

The data of a total of 193 fattening pigs were recorded, of which 133 Hz frequency was displayed in 159 cases and 150 Hz was displayed in 34 cases. The slight difference between set and displayed data is the consequence modifying effect of impedances inbuilt the circuit. Comparing *adequate/non-adequate* and *acceptable/non-acceptable* stuns, respectively, we found that *adequate* ($\text{chisq}=12.22$, $\text{Df}=1$, $\text{P}=0.0005$) as well as *acceptable* ($\text{chisq}=7.64$, $\text{Df}=1$, $\text{P}=0.0057$) stuns had significantly lower incidence on higher frequency. Frequency did not have effect on effectiveness of stunning neither before nor after sticking.

The joint effect of different frequencies with other parameters (current intensity, duration of load, stun-to-stick period) on efficiency of stunning as well as on maintenance of unconsciousness was also studied. Such correlations could not be established, viz. the frequency did not show joint effect with the other variables.

3.3. Trial 3

3.3.1. Duration of stunning

There was no significant correlation between duration of load and effectiveness of stunning either at *adequate* or at *acceptable* level at the three monitoring points at neither of the slaughterhouses.

3.3.2. Stun to stick period

The stun-to-stick period varied between 32 and 85 secs on slaughterhouse **A**.

Before sticking 44 *adequate* and 115 *non-adequate* cases were recorded, whereas 104 *acceptable* and 55 *non-acceptable* cases.

At *acceptable* level the maintenance of unconsciousness decreased significantly when the stun-to-stick period increased (correlation-test, $P=0.0258$). This effect was proved by logistic

regression, whereas at *adequate* level this effect could not be proved.

In addition to the foregoing another question may arise: what is the interval between end of effective stunning and recovery of consciousness and nociception. In order to answer this question, data of *adequate* and *acceptable* stunning were analyzed. It was found that at *acceptable* level the maintenance of unconsciousness decreased significantly when the stun-to-stick period increased. On this basis an attempt was made to calculate the minimum time interval beyond which the effectiveness of anesthesia declines. Because the calculated limit value fell in a negative region and the smallest real value found was 32 sec, we may only conclude that the optimum time for start of bloodletting is within 32 sec after conclusion of stunning.

The joint effect of the stun-to-stick period with other parameters (current intensity, electric work) on maintenance of unconsciousness was also studied. At *acceptable* level the stun-to-stick period had significant joint effect with current intensity (chisq=4.58, Df=1, P=0.0323). Higher amperage caused longer maintenance of unconsciousness, while extended stun-to-stick period shortened the maintenance of unconsciousness.

After sticking 33 *adequate* and 126 *non-adequate* cases were found, while 83 *acceptable* and 76 *non-acceptable* cases proved.

In spite of results before sticking, the stun-to-stick period did not have significant effect on the maintenance of unconsciousness after sticking. We examined the joint effect of the stun-to-stick period with other parameters (current, electric work) on the maintenance of unconsciousness until bleeding. Neither current nor electric work had significant joint effect.

3.3.3. Fulltime

On slaughterhouse **A** effect of fulltime was checked too. Number of cases are identical with previous point.

Before sticking, at *adequate* level there was no significant correlation with maintenance of unconsciousness. Fulltime did not have significant joint effect either with current intensity or with electric work. At *acceptable* level, fulltime and the maintenance of unconsciousness did not show significant correlation; however, a decreasing tendency were seen, and the joint effect of fulltime and current intensity was significant (chisq=4.62, Df=1, P=0.0316). Interaction was found between fulltime and current intensity: the lower the amperage, the shorter the period of unconsciousness (P=0.0141). **After sticking**, fulltime did not

have significant correlation with the maintenance of unconsciousness either alone or jointly with other parameters.

3.3.4. Current and electric work

Results regarding current intensity and electric work are presented together, because amperage was measured while the electric work was calculated.

Current intensity was between 0.35 and 2.57 A. As for electric work, values between 358 and 10,036 Wattsecundum (= Joule) were calculated.

3.3.4.1. Data after stunning

After stunning 153 *adequate* and 143 *non-adequate* cases were recorded, whereas at *acceptable* level 282 *acceptable* and 14 *non-acceptable* cases were found.

Analysis of pooled and separate data of the two slaughterhouses showed that increasing current intensity had significant effect on effectiveness of stunning. This significant effect of current intensity was detected both at *adequate* and *acceptable* levels (correlation-test, $P=0.0000$, ill. $P=0.0005$). Electric work and the effectiveness of stunning showed the same correlation: higher electric work resulted in significantly better stunning both at *adequate* and *acceptable* levels (correlation-test, $P=0.0000$ and $P=0.0035$, resp.).

Accuracy	90%	95%	99%
Minimum required current (A) at <i>adequate</i> level	1.61	1.91	2.55
Minimum required current (A) at <i>acceptable</i> level	0.51	0.67	1.02
Minimum required electric work (J) at <i>adequate</i> level	6 074.09	7 525.13	10 730.64
Minimum required electric work (J) at <i>acceptable</i> level	5 74.51	1 578.49	3 796.4

Table 1 Minimum required current and electric work for effective stunning at different level with different accuracy (A = ampere, J: joule)

Logistic regression showed no effect of slaughterhouses on either amperage or electric work and the same negative correlation was found between location (slaughterhouse) and efficiency of stunning. Consequently, minimum required current and electric work for effective stunning could be established irrespective of the location (**Table 1**).

3.3.4.2. *Data before sticking*

Maintenance of unconsciousness were found *adequate* in 86 and *acceptable* in 225 cases, while 210 and 71 cases were *non-adequate* and *non-acceptable*, respectively.

The analysis of pooled data showed that increasing current intensity had significant effect on effectiveness of stunning at both levels (correlation-test, $P=0.0000$, $P=0.0000$, resp.). When data found at different slaughterhouses were analyzed separately only a tendency was found, i.e. the effect of current intensity on the maintenance of unconsciousness was statistically not proven. The same interactions were found with data of electric work.

According to the results of logistic regression, at *adequate* level difference was found between locations in terms of correlations between current intensity and electric work, which was not significant but was regarded as a block effect. At *acceptable* level the effect of location was significant on both the correlation between current intensity and effectiveness ($\text{chisq}=9.54$, $Df=1$, $P=0.0020$) and between work and effectiveness ($\text{chisq}=10.86$, $Df=1$, $P=0.0010$). Consequently, the minimum current intensity and electric work required for effective stunning could be established only by location and with different accuracy.

As the stun-to-stick period was variable in slaughterhouse **A**, an attempt was made to correlate the effects of current intensity/electric work with the duration of load, stun-to-stick period or fulltime. No such correlation was found.

3.3.4.3. *Data after sticking*

Maintenance of anesthesia after sticking was found adequate in 69 and acceptable in 178 cases and non-adequate in 227 and non-acceptable in 118 cases, respectively.

Descriptive statistical analysis of pooled data showed that efficiency of stunning increased significantly with increasing current intensity at both levels (correlation-test, $P=0.0003$, $P=0.0000$, respectively). Data analysis by location revealed that current intensity had significant effect but only in one of the slaughterhouses and only at *acceptable* level. The correlation between electric work and effective maintenance of unconsciousness was similar, i.e. increasing electric work significantly improved the effectiveness both at *adequate* and *acceptable* levels (correlation-test, $P=0.0002$, $P=0.0000$, respectively). When data were analyzed by location, the electric work had significant effect at one of the slaughterhouses at *acceptable* level.

Logistic regression showed that current intensity interacted partly with the location (chisq=23.92, Df=1, P=0.0000) and partly with the duration of stunning (chisq=25.96, Df=1, P=0.0000). It follows that no opportunity was found to calculate the minimum current intensity required for the maintenance of efficient anesthesia after bleeding. For electric work no such interaction was found, and therefore the minimum electric work required for the maintenance of efficient anesthesia after bleeding was calculable. The data are shown in **Table 2**.

Accuracy	90%	95%	99%
Minimum required electric work (J) at <i>adequate</i> level	9 374.55	10 961.06	14 465.84
Minimum required electric work (J) at <i>acceptable</i> level	4 515.59	5 629.23	8 089.38

Table 2 Minimum required electric work for maintenance of unconsciousness beyond sticking at different level with different accuracy (J = joule).

The stun-to-stick period varied at slaughterhouse **A**, the interaction between maintenance of unconsciousness after bleeding and parameters including current intensity, duration of

stunning or the time interval between end of stunning and bloodletting could not be proved statistically.

4. Discussion

The effect of current intensity is unambiguously significant to efficiency of stunning. Other parameters such as voltage and impedance of head have shown no significant connection to effectiveness.

No correlation was found between duration of stunning and the effectiveness of stunning in the range examined (3 to 35 seconds). Because no stuns shorter than 3 sec were tested in this study, the 3-sec minimum duration of stunning recommended earlier is still regarded valid. The common belief of slaughterhouse workers, i.e. the longer the stunning, the better the result, was not verified by the present investigation.

The increase of electric work also has significant effect on effectiveness of stunning. However, as duration of stunning was not demonstrated to have effect, the positive effect of electric work is attributed to the current intensity.

Frequency of stunning current also has significant role in effectiveness of stunning, i.e. higher frequency (around 300 Hz) results in less effective stunning in comparison with lower

frequency (150 Hz). We ascertained that frequency had no effect on maintenance of narcosis but only efficiency of stunning. In case of 150 Hz, the stunning device used for our trial produced 6 milliseconds long periods, from which the positive half-wave lasted for 3 milliseconds. In case of 300 Hz, one period was 3 milliseconds including 1.5 millisecond long half-wave. This time is not long enough to form a standing depolarization in neurons.

The minimum current intensity required for effective stunning is important from the practical point of view. In the one hand current is not acceptable as an exclusive prerequisite of good electrical stunning of pigs because other parameters (e.g. frequency and electric work) have also influence. On the other hand 1.3 A as minimum required current could not be confirmed under commercial conditions. In order to achieve proper flow of current in the brain adequate positioning of tongs (viz. between the eyes and the base of the ears) has distinguished importance. Provided that the tongs are correctly positioned, stunning is *acceptable* in 99% of the cases if minimum current intensity and electric work is 1.02 A and 3,796 J, respectively.

Analysis of the maintenance of unconsciousness until sticking showed that the current intensity used for stunning also has crucial role. However, we concluded that minimum thresholds could be established only by location. Besides, it seems that the

maintenance of unconsciousness is also influenced by the stun-to-stick period. This is shown by the fact that increasing the stun-to-stick period significantly decreased the incidence of effective maintenance of unconsciousness. On the other hand, stun-to-stick period and fulltime showed significant joint effect (negative correlation) with current intensity: higher current intensity caused better maintenance of unconsciousness, while a longer stun-to-stick period had the opposite effect. This joint effect can explain the fact that current thresholds could be established only by location, because stun-to-stick period can be different in different slaughterhouses.

The recovery of consciousness is more probable if the stun-to-stick period is longer: the time of sticking must be somewhere within 32 seconds after the end of stunning.

Electric work had similar effect as current intensity on the maintenance of unconsciousness until sticking, which can be attributed to the fact that current intensity is one of the variables used for calculating the electric work.

Current intensity also had considerable impact on the maintenance of unconsciousness beyond sticking. However, in addition to current intensity location and duration of stunning also had influence at that monitoring point. It follows that it was not

possible to establish a threshold for current intensity. This can be explained again by the fact that stun-to-stick period can be different in different slaughterhouses. This problem might be overcome by establishing figures for electric work. In 99% of the cases unconsciousness can be maintained on an acceptable level beyond sticking when the electric work is at least 8,089 J. The effects of current intensity and stunning duration are combined in the electric work. The electric resistance inbuilt in a circuit transforms electricity into heat. In our case the head and its tissues and cells create electric resistance in head-only stunning. The heat causes coagulation necrosis and denaturation of proteins in cells and tissues. It is assumed that the tissue destruction caused by electric work might play role in maintenance of unconsciousness beyond sticking, even in cases when bloodletting starts beyond 32 seconds after conclusion of stunning.

In summary, on basis of these investigations conducted under commercial conditions we may conclude that current intensity plays predominant role in the effectiveness of stunning and also in the maintenance of unconsciousness. Duration of stunning is a parameter involved in the electric work. The importance of electric work is shown in the long-lasting maintenance of unconsciousness. Setting of stunning devices cannot be

standardized. Parameters ensuring proper unconsciousness can be established only by location by means of animal based measures.

5. New scientific results

1. We verified under commercial conditions that efficiency of head-only electrical stun of pigs is determined primarily by current.
2. We verified under commercial conditions that stunning is effective on lower frequency and not effective on higher frequency.
3. We established a new threshold for current (1.02 A), which is needed for acceptable head-only electrical stuns if positioning of tongs is between the eyes and the base of the ears.
4. We verified that 32 seconds after stunning pigs surely start regain consciousness and nociception.
5. We confirmed that electric work plays role also in the maintenance of narcosis after head-only electrical stuns of pig, and its proposed minimum threshold is 8089,38 J.

6. Own scientific publications related to the topic of the present thesis

a) Full text papers in peer-reviewed journals

Vegh, A., Abonyi-Toth, Zs., Rafai, P.: Verification of the technical parameters of head-only electrical stunning of pigs under commercial conditions. *Acta Vet. Hung.*, 58. 147-56, 2010.

Vegh, A., Abonyi-Toth, Zs., Rafai, P.: Effect of current and duration on the efficiency of head-only electrical stunning in pigs under commercial conditions. *Acta Vet. Hung.*, 2016. (Submitted paper)

Végh Á.: Animal welfare – scientific concepts. *Magyar Állatorvosok Lapja* 134. 741–750, 2012.

Végh Á., Abonyi-Tóth Zs., Rafai P.: Effect of frequency at head only electrical stunning of pigs on the efficiency of stunning in commercial conditions. *Magyar Állatorvosok Lapja*, 2016. (Accepted paper)

Jurkovich V., Fóris B., **Végh Á.**: Methods for assessing animal welfare in dairy cattle herds. Literature review. *Magyar Állatorvosok Lapja* 134. 442–448, 2012.

Jurkovich V., Fóris B., **Végh Á.**, Kovács P., Könyves L., Brydl E.: Assessing welfare quality in Hungarian dairy cattle herds. *Magyar Állatorvosok Lapja* 134. 605–613, 2012.

b) Full text papers

Weber M., Jurkovich V., Fóris B., Szklenár A., Hadfi Zs., Fazekas N., **Végh Á.**: The protocols of welfare quality® – improving measurements of animal welfare. Animal welfare, ethology and housing systems, 9. 76-82, 2013.

c) Book

Végh Á.: Animal welfare officers on farms – based on requirements of Decree 32/1999. (III.31.) of Minister of Agriculture and Rural Development. NÉBIH, Budapest, 2012.

d) Conference abstracts

Végh Á.: Definition and measurement of farm animal welfare, IIIrd Gödöllő Scientific Breeding Days, Gödöllő, 2011.

Végh Á.: Welfare aspects of pig keeping, Köves-days, Siófok, 2012.

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