Developing a safe and acceptable method for on-farm euthanasia of pigs by electrocution

Final report

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Glossary

Alternating current (AC)*: an electric current that reverses its direction many times a second.

Ampere (Amp, A)*: the SI base unit of electric current, equal to a flow of one coulomb per second

Clonic: of the nature of clonus, marked by contraction and relaxation of muscle

Clonic phase: phase where there are repetitive muscular contractions and relaxations in rapid succession

Convulsion*: a sudden, violent, irregular movement of the body caused by involuntary contraction of muscles. A convulsion may be either tonic or clonic.

Current (electric)*: a flow of electrically charged particles. Current is either alternate or direct. The strength or density of the current is measured in amperes (A).

Direct current (DC)*: an electric current flowing in one direction only

Electrification*: to charge with electricity

Electrocution*: injury or killing by electric shock

Electronarcosis: profound stupor or unconsciousness produced by passing an electric current through the brain.

Euthanasia: painless death. From Greek *eu* 'well' + *thanatos* 'death'

Flaccid*: soft and limp

Frequency*: the rate per second of a vibration constituting a wave, e.g. sound, light, or radio waves. Measured in Hertz

Gasps (agonal): the spasmodic open mouth with contraction of the diaphragm and retraction of the hyoid apparatus which occurs at death (Saunders Comprehensive Veterinary Dictionary, 3 ed. © 2007)

Impedance*: the effective resistance to an alternating electric current arising from the combined effects of ohmic resistance and reactance. Measured in ohms (Ω).

Multimeter: an electrical measuring device that combines an ammeter, an ohmmeter, a voltmeter, and occasionally other measurement or testing devices into one unit. (American Heritage® Science Dictionary)

Myoclonia*: a rapid involuntary non-rhythmic spasm that can occur spontaneously at rest, in response to sensory stimulation, or with voluntary movements (McGraw-Hill Concise Dictionary of Modern Medicine.)

Nystagmus: involuntary, rapid, rhythmic movement (horizontal, vertical, rotatory, or mixed, i.e., of two types) of the eyeball. (Dorland's Illustrated Medical Dictionary, 30th ed.)

Ohm*: the SI unit of electrical resistance, transmitting a current of one ampere when subjected to a potential difference of one volt. (Symbol: Ω)

Opisthotonos*: a prolonged severe spasm of the muscles causing the back to arch acutely, the head to bend back on the neck, the heels to bend back on the legs, and the arms and hands to flex rigidly at the joints (Mosby's Medical Dictionary)

Paddling: action of pushing on the ground using a leg. In our evaluation, paddling is defined as a sequence of more than 3 movements of one or more of the animal’s limbs during the convulsions following electrocution

Tonic phase: a phase characterized by continuous tension or contraction of muscles, as a convulsion or spasm (The American Heritage® Medical Dictionary)

Resistance*: the degree to which a material or device opposes the passage of an electric current. Measured in ohms Ω. (The term « resistance » is used for direct current; « impedance » is used for alternating current.)

Stunning: loss of function, analogous to unconsciousness (Dorland’s Illustrated Medical Dictionary, 30th ed.)

Tonic: characterized by continuous tension or contraction of muscles

Transformer*: a device for changing the voltage of an alternating current by electromagnetic induction

Volt* (V): the unit of electromotive force in the SI system, the difference of potential that would carry one ampere of current against a resistance of one ohm.

Voltage* (V): an electromotive force or potential difference expressed in volts.

Note: definitions preceded by an asterisk (*) are taken from the Compact Oxford English Dictionary

Abbreviations

A	ampere
AC:	alternating current
CDPQ:	Centre de développement du porc du Québec inc.
CO_2:	carbon dioxide
EEG:	electroencephalogram
ECG:	electrocardiogram
e.g.:	for example
FPPQ:	Fédération des producteurs de porcs du Québec
Hz:	hertz
kg:	kilogram
mA:	milliampere
mg:	milligram
mm:	millimeter
ms:	millisecond
R:	resistance
RC:	resistance-capacity
s:	second
SPEE:	Safe and painless euthanasia by electrocution
µA:	microampere
V:	volt
VAC:	volt in alternating current
VDC:	volt in direct current

Abstract

Euthanasia of compromised pigs is a procedure which is commonplace on the farm. The goal of our project was to develop a one-step method of euthanasia by electrocution using a domestic source of electrical current (110 VAC or 220 VAC). The technique had to make it possible to electrocute pigs from 5 to 105 kg and had to respect requirements for pig welfare, for social acceptability and for worker safety.

The work was carried out on 91 compromised commercial pigs over 5 kg. To start with, the connections (electrodes and contact points) with the greatest potential for electrocution were identified by estimating the impedance at low voltage (6 VAC) on living anaesthetised pigs. The connectors selected were: 1) anal probe combined with a steel lasso placed around the upper jaw; 2) metal belt around the abdomen combined with the lasso around the upper jaw. These techniques allowed for efficient electrocution of pigs from 5 to 105 kg. Circulating current was similar for both methods (average of 0.96 amp, minimum of 0.55 amp, maximum of 1.42 amp), but it was influenced by the weight of the pigs. The stronger currents were measured on heavier pigs. When an electrocution is carried out successfully, the following motor activities can be observed: tonic phase (during and following electrocution), collapse of the animal, a phase of muscular spasm without paddling with gradual loss of all muscle tone until an irreversible flaccid phase is reached.

After the current was shut off, all pigs showed dilated pupils and were in cardiac fibrillation. There were no corneal, nociceptive or respiratory reflexes. All of these observations suggest that electrocution is a very effective method for the technical slaughter of pigs.

The connection using a lasso around the upper jaw and a metal abdominal belt was chosen for development of a safe mobile unit (SPEE: Safe and Painless Euthanasia by Electrocution) which works with a 12 V battery and a transformer. An insert for the technical information sheet of the *Fédération des producteurs de porcs du Québec* about pig euthanasia on the farm outlining the technique of euthanasia by electrocution was produced. As well, training for pork producers was updated in order to present the SPEE.

1 Introduction

In recent years, the conditions in which swine are raised, shipped and slaughtered have become a growing public preoccupation. In animal production, it is unfortunately impossible to entirely prevent some animals from being wounded or falling sick. In order to put an end to unnecessary suffering, it is necessary to euthanize them. Further, given the recent Canadian regulations governing the transportation of animals, it is no longer possible for a producer him or herself to transport or to have a third party transport a compromised animal if the shipping might lead to unnecessary suffering. An increasingly rigorous application of this policy by the Canadian Food Inspection Agency (CFIA) has caused an increase in the number of euthanasia of compromised swine that must be carried out at the farm site.

For on-farm euthanasia, norms and recommendations have been set down according to species, age and state of health of the animals in question. To be acceptable, procedures for euthanasia must avoid any situation that may cause over-stimulation, fear or suffering for the animal. The animal's confinement must be minimal and not stressful. The procedure for euthanasia must cause rapid loss of consciousness followed by quick death (AVMA, 2001). The animal must not suffer or have a prolonged death. The procedure for euthanasia must be effective, simple to carry out, safe for the operator, irreversible for the animal and, if possible, affordable. Lastly, the overall appearance of the procedure must not be neglected. If the method is to be acceptable, both to the person in charge of the euthanasia and to the general public, it must not look repulsive or cruel.

The Quebec guide « Euthanasie des porcs à la ferme : les options du producteur » (FPPQ, 2003), the American guide « On farm euthanasia of swine – Options for the producer » (AASV and NPPC, 1997) as well as the French guide « Euthanasie en élevage de porcs » (Chevillon *et al.*, 2004) recommend different methods for on-farm euthanasia. The procedures recommended by these guides include several methods of cranial trauma (firearms, captive bolt pistols, stunning), overdose of anaesthetics (only under supervision by a veterinarian), CO_2 intoxication and electrocution.

The proposed rules to carry out electrocution of swine are based on work done to optimize electrical stun techniques used on swine prior to slaughter. To our knowledge, there is no commercial device specifically designed for the on-farm electrocution of compromised swine. However, for several years some Quebec producers have adopted various home-made techniques using 110 or 220-volt readily-available power sources, without having properly mastered the technique.

Generally, experts in animal welfare do not consider electrocuting swine with a 110 or 220-volt power source adequate. As well, current on-farm techniques are unsafe. As mentioned above, this situation is essentially due to lack of information and reliable data showing the effectiveness of a technique of swine electrocution. Preliminary work carried out by Denicourt *et al.*, (2006) suggests that it is possible to effectively electrocute swine using a 110 VCA power source when the electrodes are applied to the right places.

The goal of this project is to develop and refine a turnkey method of euthanasia for compromised swine at the farm site that respects the requirements concerning swine welfare, public acceptability, worker safety and affordable cost.

2 Literature review

2.1 Putting animals to death

Various situations justify or require killing animals. The main ones are:

> 1) In a clinic: euthanasia of pets; 2) On the farm: wounded or compromised animals; 3) Animal welfare societies and refuges: overpopulation, abandonment, medical reasons; 4) Animal production: slaughterhouses, fur industry; 5) Pathology and necropsy laboratories; 6) Emergency and other extreme situations: e.g., seriously wounded animals, road accidents, natural catastrophe, beached marine mammals; 7) Wildlife: population control or epizootic control; 8) Sanitation crises: mass euthanasia during epidemics, e.g., foot-and-mouth disease, bird flu; 9) Research: in this particular context, the needs as determined by the objectives of the experiment and the experimental protocol; 10) Teaching: although more and more infrequent because of alternative methods, sacrificing animals is still used for teaching at various levels of instruction (adapted from Kona-Boun, 2005).

There is abundant literature about on-farm euthanasia for meat production (situation #4). This research project is mainly interested in the problems of culling swine in on-farm situations (situation #2). It should be noted that in French journals, the authors often use the term « abattage technique » (technical slaughter) to describe killing animals at the farm. The reader must understand that the regulations and technical constraints of the two situations are very different.

At the slaughterhouse, it is imperative to maintain cardiac function during bleeding to maximize elimination of blood and thus ensure good meat quality. In addition, slaughter techniques must be very rapid to allow for slaughter of a large number of animals in a short time. On the farm, the main restrictions are more related to the simplicity and acceptability of the procedure without having to take meat quality into account.

The death of the animal must be attested by an examination whose purpose is to diagnose the cessation of vital signs (AVMA, 2001). The absence of heartbeat and breathing along with the absence of reflexes are good indicators of irreversible death (Close *et al.*, 1996).

There are various techniques, both time-honoured and modern, for killing animals at the farm. In modern societies, experts favour techniques which minimize the animal's suffering and stress. The more acceptable techniques for killing animals are usually described as « euthanasia ».

2.2 Euthanasia

The term « euthanasia » comes from the Greek words eu (good) and thanos (death). Thus euthanasia is defined as a « good death ». The various euthanasia techniques can be classed under three headings according to the means used to carry out the act: 1) cerebral hypoxia, direct or indirect; 2) direct depression of neurones necessary for life; 3) physical disruption of brain activity and destruction of the neurones necessary for life (Kona-Boun, 2005). This last category is usually described as « physical methods ».

For on-farm euthanasia, various organisations have proposed norms and recommendations depending on species, age or the state of the animal's health (Working Party Report, 1996; AVMA, 2001). Accepted procedures for euthanasia must avoid any situation that may cause over-stimulation, fear or suffering of the animal. The animal's confinement must be minimal and not stressful. The procedure for euthanasia must bring rapid loss of consciousness followed by quick death (AVMA, 2001). The animal must not suffer or have a prolonged death. The procedure for euthanasia must be effective, simple to carry out, safe for the operator, irreversible for the animal and, if possible, affordable. Lastly, the overall appearance of the procedure must not be neglected. If the method is to be acceptable, both to the person in charge of the euthanasia and to the general public, it must not look repulsive or cruel.

The Quebec guide « Euthanasie des porcs à la ferme : les options du producteur » (FPPQ, 2003),the American guide « On farm euthanasia of swine – Options for the producer » (AASV and NPPC, 1997) as well as the French guide « Euthanasie en élevage de porcs » (Chevillon *et al.*, 2004) recommend different methods for on-farm euthanasia. The procedures recommended in these guides include several methods of cranial trauma (firearms, captive bolt pistols and stunning), overdose of anaesthetics (only under supervision by a veterinarian), CO_2 intoxication and electrocution.

Traumatic methods such as cerebral trauma by cranial shock, bolt pistol and sometimes even firearms are the most commonly used procedures on the farm because they are the most affordable. However, their use on the farm is not always clear and straightforward since the technical and visual aspects of their use repel many producers. Methods of euthanasia involving stunning create an impression of uncivilised brutality. As well, cranial trauma (stunning) is bloody and animals euthanized by this method usually show paddling and kicking reflexes, leaving the impression that they may be suffering. Finally, where pigs over 70 kg are concerned, it is recommended to bleed the animal after trauma in order to ensure that it is dead. These rather repulsive technical aspects of the cull very often bring about useless delay in euthanizing compromised animals and thus bring about unnecessary suffering.

This research project is mainly interested in the technique of swine electrocution often classed among the « physical methods » (Croft and Hume, 1956, cited in AVMA, 2001). As generally described in the literature, the electrocution technique is carried out in two phases. First, the operator runs current through the animal's head to stun it (to induce insensibility) and then he or she completes the process of putting the animal to death by exsanguination or bleeding out (e.g., at the slaughterhouse) or by applying electrical current to the heart area to bring on cardiac fibrillation. With the first method, the exsanguination causes death; with the second, death is caused by cardiac fibrillation.

It is important to understand that the current flowing through the animal's head disturbs brain activity but does not bring about death. Speaking technically, we must draw a clear distinction between electrification and electrocution (Wikipédia, 2009). « Electrification », in the medical literature, describes the concept of current flowing through a body without bringing about the animal's death. When the current is strong enough to cause death, the term « electrocution » is used. The flow of electrical current through an animal's head may bring on loss of consciousness usually described as « electrical stunning ». Most of the techniques described by the term « electrocution » are in fact techniques of electrical stunning followed by some other process (e.g., exsanguination) to guarantee the animal's death. Electrical stunning is the most commonly used technique in slaughterhouses to induce unconsciousness animals prior to exsanguination.

2.3 Electrical stunners

Several devices have been developed to stun swine by electrification. Some devices are complex and are integrated into the slaughtering process while others are mobile, smaller and designed for smaller slaughterhouses. This review will limit itself to describing smaller systems since any description of technology used in the modern commercial slaughtering process falls outside the framework of this project. And, in any case, such technologies do not apply to the farm.

Mobile electric stunners usually consist of a transformer, safety equipment and two electrodes which are applied to the animal's head (Figure 2-1). There are two main concepts when it comes to electrical stunning of swine: 1) two electrodes applied to the animal's forehead (Figure 2-1a) and clips applied to both sides of the animal's head (Figure 2-1b).

Figure 2-1. Examples of electrical swine stunning equipment for slaughterhouses

a) Electric stunner (Best & Donovan model ES) with two contact electrodes

b) Commercial stunning tongs (Karl-Shermer) for electrical swine stunning

2.4 Stunning

Stunning is the term which describes the process of rendering an animal unconscious and insensitive. According to several writers, it is more appropriate and less anthropomorphic to use the expression « loss of sensibility » rather than « loss of consciousness » to describe the state of animals that have been numbed and that can no longer perceive pain (Blackmore and Newhook, 1983). Moreover, some writers use the term « electronarcosis » to describe the insensitivity of animals after electrification.

Directive 93/119/EC from the Council of the European Union defines stupor as any process which, when applied to an animal, causes an immediate loss of consciousness which continues until the animal's death (Conseil de l'Union Européenne, 1993). In most cases where animal species are destined for human consumption, the animal is put to death in two stages: unconsciousness or electric stunning and then death by exsanguination.

Level of consciousness may be evaluated by observing the animal's behavioural signs (voluntary motor activity and reflexes) and the electrical activity of its brain (Knudsen, 2005). The clinical signs indicating the success of electrical stunning are: immediate collapse of the animal, tonic and clonic phases of the epileptiform seizure, dilation of the pupil, absence of corneal reflexes and nociception, lack of respiration, disappearance of pulse, a complete relaxation of the carcass and, sometimes, frothing at the mouth, urination and defecation (Lambooy, 1981). The report of the European Food Safety Authority stresses that respiratory spasms and corneal reflexes which may be noticed for a short while, are signs of the death of the brain rather than of a return to consciousness or sensitivity (EFSA, 2004).

2.4.1 Epileptiform activity

If we run a high enough flow of electric current through the brain of an animal, it will cause unconscious by bringing on epileptiform activity. The main phases of epileptiform activity are the tonic phase, the clonic phase and return to consciousness (Croft, 1952; Wotton, 1995; EFSA, 2004). According to Croft (1952), there is, as well, a relaxation phase which precedes the return to consciousness. The animal is recognisably unconscious during the tonic and clonic phases.

2.4.1.1 Tonic phase

The tonic phase is characterized by a stiffening of the muscles in the electrified region. The tonic phase begins as soon as electrical current is applied and may continue for several seconds after the current has been shut off (adapted from Croft, 1952; Wotton, 1995; EFSA, 2004). While current is being applied, the animal‘s whole body becomes rigid, breathing stops and the eye position becomes fixed. The head lifts up and the rear legs are bent under the body. The forefeet may, at the onset, be bent, but they usually end up by stretching out towards the exterior. The average length of the tonic phase as reported by various writers during electrical stunning is 10 seconds using domestic frequency (50 Hz) (Table 2-1).

2.4.1.2 Clonic phase

The clonic phase is characterized by a loss of muscle tone and by the presence of slight and/or severe muscle trembling where the term paddling or kicking would be more appropriate (adapted from Croft, 1952; Wotton, 1995; EFSA, 2004). Intuitively, the term « clonic phase » refers to paddling and/or to abrupt movements. However, the term « clonic » may also indicate myoclonia which refers to muscular trembling without movement of the trunk or legs.

The length of the tonic and clonic phases varies widely from one animal to another (Wotton, 1995). Some animals may show leg movement and even paddling that may last between 15 and 45 seconds. Such movements are purely involuntary and uncontrollable. They are a sign that the central nervous system has completely lost control of the spinal cord (Chevillon, 2005). The average length of the clonic phase is 28 seconds, as reported by various writers when stunning swine (Table 2-1).

Table 2-1. Description of the duration of the clonic and tonic phases during stunning of swine by electrification with different sources of alternating current (Volts in alternating current – VAC at 50 Hz)

			Electrocution		Average duration	
Electrode position	Weight (kg)	N	VAC	Duration	Tonic	Clonic
Between forehead and thorax [1]	70 - 80	16	200	3	9	34
Between forehead and thorax [1]	70 - 80	22	200	3	10	30
Between forehead and thorax [1]	70 - 80	18	200	3	10	35
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	13	100	3	11	31
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	18	100	7	13	27
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	13	100	3	8	34
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	18	100	7	9	30
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	20	150	3	10	27
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	22	150	7	10	24
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	20	150	3	7	32
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	22	150	7	8	27
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	21	300	3	11	21
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	21	300	7	18	18
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	21	300	3	8	27
Between the lateral canthus of the eye and the ear [2,3]	60 - 80	21	300	7	11	26
Average duration ± standard deviation					10 ± 3	28 ± 5

[1] McKinstry and Anil, 2004; [2] Anil, 1991a; [3]forelegs; [4] hind legs

2.4.1.3 Return to consciousness

Respiration is interrupted during the tonic and clonic phases. If the animal has not been put to death during the unconsciousness period which lasts approximately 38 seconds (tonic phase + clonic phase – see table 2-1), the animal may regain consciousness (Wotton, 1995). The first sign of consciousness is a return to rhythmic breathing (Anil, 1991a; Anil and McKinstry, 1992; Anil *et al.*, 1997). Anil *et al.*, (1997) estimate that the return to rhythmic breathing is not as reliable as the corneal reflex as an indicator of gradual return to consciousness. Return to rhythmic breathing would occur approximately 40 seconds after electrical stunning of swine for 3 to 7 seconds with a 150 VAC current source (Anil, 1991a).

The animal goes through three distinct stages when it returns to consciousness after electrical stupor (adapted from Croft, 1952). First, it is completely unconscious and shows no reflexes. Then, the animal feels pain without being able to react because its voluntary muscles are paralysed. Finally, the observer will notice the return of reflex movements involving the involuntary muscles.

2.4.2 Loss of muscle tone and vocalization

When the animal loses consciousness, the loss of muscle tone brings on immediate collapse and it is possible to observe a slackening of the anal and urinary sphincters (Chevillon, 2005). A completely relaxed jaw is a good indicator of brain dysfunction and a clear sign of loss of consciousness (Gregory, 1998). The animal will show a flaccid and elongated tongue and should produce no vocalization throughout the whole process of stunning and death. Vocalization is an indicator of inadequate stunning.

2.4.3 Mydriasis and corneal reflex

A stunned animal shows a dilated pupil (mydriasis) which retracts as the animal regains consciousness (EFSA, 2004). During the pre-slaughter stun period, it is important that the pupil of the stunned animal remains dilated up until death (Chevillon, 2005).

The first sign when an animal is insensible is the disappearance of the natural blinking of the eye (Grandin 2004). After that, the operator can test the animal's insensibility using a corneal reflex test. In a normal animal touching the cornea causes the eyelids to close. This normal reflex disappears when an animal is insensible. According to Gregory (1998), some insensible animals can still show a corneal reflex, but its absence is certainly a good indicator that the animal is unconscious since it suggests profound brain dysfunction. Generally, a return of the corneal reflex occurs shortly after the return of regular rhythmic breathing (Anil, 1991a).

2.4.4 Nociception

Another means of confirming the loss of consciousness involves repeatedly pricking the animal's snout using a needle to detect a response to pain stimulus. The normal response from a conscious animal would be a backward movement of the head. Thus, the absence of response to stimulation with a hypodermic needle is one of the signs which allow us to confirm the effectiveness of electrical stunning (EFSA, 2004)

2.4.5 Respiration

The cessation of the respiratory system is another indicator of the unconsciousness of the animal.

2.4.6 Abnormal electrical brain activity

The decrease or loss of the brain's electrical activity is often mentioned as a good indicator of an animal's unconscious. An electroencephalogram (EEG) recording is proposed as a complementary tool to document two situations: 1) an indicator which complements observation of the animal's behaviour in order to confirm the effectiveness of the electrical stunning or of the electrocution; 2) an indicator of the animal's awakening after stunning by electrification. The following comments from various writers show the both the benefits and the difficulties linked to measuring and interpreting EEGs when stunning animals electrically.

According to the EFSA (2004) report, an animal may be judged unconscious and insensible by EEG analysis if at least one of the two following conditions is met. The first condition is that the EEG shows changes that are incompatible with consciousness, as when the large amplitude, weak frequency waves or a prolonged period of inactive brain with less than 10% of the pre-stunning energy content (flat or isoelectrical waves) are observed. The second condition is the absence of any electrical brain response to auditory or visual stimuli.

According to Lambooy (1981), since electrical stunning of an animal can set off reflex movements but can also cause paralysis, the degree of consciousness of an animal that has been electrically stunned should not be attested solely by observing its behaviour or its reflexes. Recording electrical brain activity (EEG) will also supply important information about the animal's level of consciousness.

da Silva (1983), too, states that, during the process of unconscious, changes to the animal's behaviour and its EEG evolve in parallel. On the behaviour side, efficient electrical stunning brings on tonic spasms followed by clonic contractions and a comatose final phase. Electrical brain activity is normal during all phases of electrical stunning (tonic and clonic). The EEG obtained during the phases shows normal pattern distortion or a total disappearance of the signal.

In electrical stunning of lambs, Lambooy (1981) shows that the EEG increases in amplitude and decreases in frequency, which is then followed by a marked decrease in electrical activity. At the same time, lambs stunned by electrocution show the following behaviour: opisthotonos (extension of the limbs); eyeballs rolled back; tonic spasm becoming clonic followed eventually by a period of tiredness with foaming at the mouth; defecation and urine flow. The animal may be considered unconscious in all of these stages. The epileptic attack is followed by a recuperative phase. The EEG pattern then shows delta (<4 Hz) and theta waves (4 – 13 Hz) alternating with wave peaks, and changing to normal frequency waves (>13 Hz). In the last experiment, the researcher mentions that he blocked or paused the electroencephalogram recordings during the electrocution in order to protect the equipment.

According to Blackmore and Newhook (1983), the majority of the most objective studies concerning the level of animal sensitivity during the slaughtering process are based on encephalogram data. However, they mention that it is impossible to record an EEG while an animal is undergoing electrical stimulation. Blackmore (1983) draws attention to the fact that several articles do not make clear what method or methods is or were used to obtain and interpret the EEG waveform.

The various studies mentioned show that, when it comes to confirming the state of animal unconsciousness, using an EEG is not necessarily as simple as it may appear. However, the various studies do confirm that an EEG provides information which complements observed changes in behaviour. As well, the studies suggest that it is difficult, if not impossible, to measure EEG during the electrification phase.

2.5 Electrocution techniques

The literature describes two techniques for electrocuting swine: a two-step and a one-step technique. Electrocution is not considered an adequate technique for euthanizing piglets (< 5 kg) (AVMA, 2001). One information source suggests that where small animals are concerned, post-electrocution cardiac fibrillation may be reversible and results in the piglets coming back to life.

2.5.1 Two-step technique

The first technique is the one we have described above and is directly derived from studies to develop and improve techniques for slaughter. First, the operator runs current through the animal's head to stun it. Second, he or she completes the procedure of putting the animal to death by applying the current to the heart area to provoke cardiac fibrillation. For this model, the cardiac fibrillation is what allows the operator to guarantee that the animal is dead. This is the electrocution technique described in some guides for swine euthanasia (AASV and NPPC, 1997; Chevillon *et al.*, 2004).

2.5.2 One-step technique

The second electrocution technique consists in running current from the head to the posterior area in only one step. The operator obtains the two desired effects to kill the animal simultaneously: induce loss of sensibility in the brain and fibrillating the heart. This technique is less well documented than the two-step technique.

In the literature, some writers report that it is possible to kill the swine by applying current to the heart area only (AASV and NPPC, 1997). However, this technique should not be used since it does not result in unconsciousness of the pigs before or while putting them to death. (AASV and NPPC, 1997).

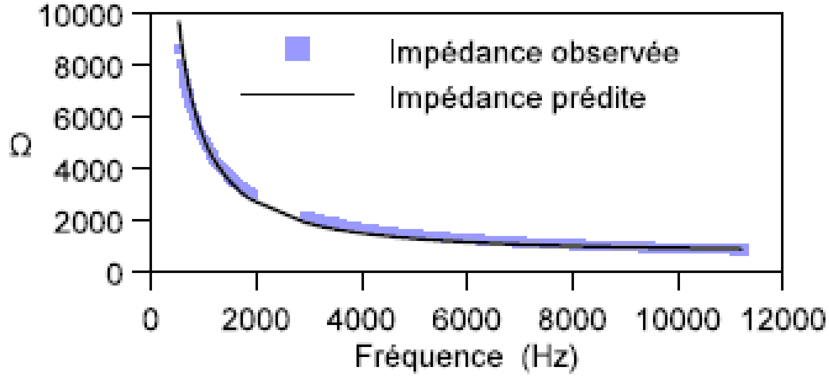
2.6 Factors that change the effects of electrical current

The main factors which govern the physiological effects of electrical current are: 1) the length of time the current is applied; 2) the strength of the current; 3) the current's path (Wikipédia, 2009; Lahouste, 2006).

> Electrical current, measured in amperes (A), represents the displacement of electrical load through matter. Electrical voltage (V) measures the potential difference between two points on an electrical circuit. The resistance of an electrical circuit, measured on ohms, represents a material's ability to limit the flow of current. By analogy, electrical current is similar to the flow of water in a river: the voltage (or power) represents the force of the water (water pressure) upstream and downstream from a power dam and the resistance represents the dam gates. When a power source is applied to an animal, the current (A) depends on the voltage (V) and the resistance (R) of the tissues between the two electrodes as laid down by Ohm's law (current = voltage/resistance) (Denicourt *et al.*, 2008).

The tissues' resistance to alternating current is described by the term « impedance ». The impedance is the sum of the purely resistant part and the reactive part of an electrical circuit (for detailed explanation, see Klopfenstein, 2003). The impedance of swine is a characteristic of their body tissue which decreases as the frequency of the alternate current source is increased (Figure 2-2).

Figure 2-2. Variation of the impedance of a sow, connected between the fore feet and the tail, as current frequency is increased



Taken from Klopfenstein, 2003

For any source of alternating current (fixed voltage and frequency) applied to a specific site (fixed path), the current flow, measured in amperes, and the length of the application will determine the physiological effects (Wikipedia, 2009). In general, it is recognized that for a domestic current source (110 or 220 VAC with a frequency of 50 to 60 Hz), the physiological effects on a human or an animal are:

- < 0.5 mA: threshold of perception;
- 0.5 à 10 mA: there is only an electric shock;
- 10 mA: the subject who is holding onto the current source (e.g., a wire) cannot release it because of irreversible muscle contraction;
- 30 mA, > 30 s: if the current flows through the rib cage, death is possible by asphyxiation because the thorax contracts;
- 75 mA, > 1 s: if the current flows through the heart, irreversible cardiac fibrillation is possible;
- 1 A: if the current flows through the heart, cardiac arrest is possible.

Adapted from: Wikipedia, 2009; Lahouste, 2006

The relation between the duration of the current and the amount of current suggests that it is the amount of electrical energy (current x time) that causes tissue damage (Wikipedia, 2009; Lahouste, 2006).

Application of these principles allows us to predict that:

- in order to decrease the required application time for stunning or electrocuting swine with a given electrode placement, the flow of the current has to be increased. Increased flow may be obtained by increasing the voltage and/or increasing the frequency of the current;
- for any given power source (fixed voltage and frequency) applied to a specific site (fixed path), the increase in the length of time current is applied increases the probability of a successful stunning and/or electrocution.

2.6.1 Duration of current flow

At the slaughterhouse, the operator tries to minimize the duration of the electrification to speed up the process of slaughtering swine. The report of the European Food Safety Authority (European Food Safety Authority, 2004) on the well-being aspect of techniques for stunning and euthanizing animals at slaughter makes the following recommendations: for a one-step procedure, voltage of at least 240 VAC should be applied to the forehead and behind the anatomical position of the heart for at least one second in order to generate a current flow of at least 1.3 A; for the two-step procedure, the first step should be done to the forehead for at least one second with a minimum voltage of 240 VAC followed by applying between 600 and 1,000 VAC to either the head and body or through the chest to guarantee very quick stunning of swine (Wotton *et al.*, 1992). These norms apply very well to slaughterhouse conditions, but the work of several researchers suggests that it is possible to stun and electrocute swine with weaker power sources and durations that are slightly longer.

The researchers tested and confirmed various electrical stunning techniques for swine with application lengths varying between 3 and 7 seconds with power sources from 150 to 300 VAC (see tables 2-1 and 2-2). Further, the work of Denicourt *et al.*, 2006 has shown that applying a 110 VAC current source for 15 seconds between the head and the posterior of the animal was a very efficient technique for electrocuting nursery and grower pigs.

A mobile electrical stunner, developed to induce unconsciousness in animals prior to slaughter, had been tested by a French team (Chevillon *et al.*, 2004) to electrocute compromised swine at the farm. They used the two-step method: 1) 350 VAC, 50 Hz current applied to the head (eye-to-eye, eye-to-ear, ear-to-ear) followed by applying current to the heart area. They report that to cause instant loss of consciousness to a pig of more than 25 kg or a sow, the current to the head must be maintained for a period of at least 5 seconds. They report, as well, that current, applied for at least 15 seconds to the heart area, will bring about cardiac arrest within a period of 60 seconds for a pig and 90 seconds for a sow.

2.6.2 Electrical intensity (amperes)

The report of the European Food Safety Authority (2004) bases its recommendations on the work of Hoenderken (1978). It recommends a minimum current strength of 1.3 A for at least a second in order to ensure electrical stunning of pigs. As previously mentioned, the researchers tested and confirmed various stunning techniques with lower current flow but with generally longer duration of application (> 1 second, Table 2-2).

The flow of current in the animal should reach its nominal level as quickly as possible and the current should not be interrupted during the application, otherwise there is a risk that the animal will feel the electric shock before being completely numb (Gregory, 2001).

Table 2-2. Description of current flow during electrical stunning of swine using various techniques and different sources of alternating current with different voltages (VAC) and frequencies (Hz)

			Electrocution mode		Measures	
Electrode position	Weight (kg)	N	VAC (Hz)	Duration	Current (mA)	Impedance (ohms)
Between an eye and the base of the opposite ear [1]	60-80	21	100 (50)	3	358	279
Between an eye and the base of the opposite ear [1]	60-80	18	100 (50)	7	448	223
Between an eye and the base of the opposite ear [1]	60-80	10	150 (50)	3	536	280
Between the bases of the two ears [2]	60-80	11	150 (50)	3	487	308
Between the two sides of the neck [2]	60-80	11	150 (50)	3	515	291
Between the top of the head and the underside of the jaw[2]	60-80	10	150 (50)	3	400	375
Between the two sides of the upper jaw [2]	60-80	10	150 (50)	3	352	426
Between an eye and the base of the opposite ear [1]	60-80	20	150 (50)	3	695	216
Between an eye and the base of the opposite ear [1]	60-80	22	150 (50)	7	859	175
Between the two sides of the neck [3]	90-100	9	180 (50)	0.5	1400	129
Between the two sides of the neck [3]	90-100	12	180 (50)	0.75	1350	133
Both sides of the head [4]	70-80	63	200 (50)	3	1050	190
Between an eye and the base of the opposite ear [2]	60-80	20	250 (50)	3	770	325
Between the bases of the two ears [2]	60-80	16	250 (50)	3	854	293
Between the two sides of the neck [2]	60-80	21	250 (50)	3	956	262
Between the top of the head and the underside of the jaw [2]	60-80	23	250 (50)	3	732	342
Between the two sides of the upper jaw [2]	60-80	13	250 (50)	3	787	318
Between an eye and the base of the opposite ear [1]	60-80	21	300 (50)	3	1926	156
Between an eye and the base of the opposite ear [1]	60-80	21	300 (50)	7	1970	152
Between the forehead and various places on the neck and back [5]	50	60	300 (50)	3.5	1640	183
Between the forehead and various places on the neck and back [5]	80	60	300 (50)	3.5	1420	211
Between the two sides of the neck [3]	90-100	11	300 (50)	0.25	2070	145
Between the two sides of the neck [3]	90-100	2	300 (50)	0.5	2340	128
Average ± standard deviation						241 ± 86
Both sides of the head [6]	110	40	240 (800)	3	2570	93

[1] Anil, 1991a; [2] Anil and McKinstry, 1998; [3] Hoenderken 1978; [4] McKinstry and Anil, 2004; [5] Wotton *et al.*, 1992; [6] Lambooij *et al.*, 1996.

2.6.2.1 Electrical power (volts)

Most commercial electric stunners are based on a power source with fixed voltage and frequency during the electrification process. Some models allow the operator to vary the voltage to adjust the strength of the current to the size of the animal (e.g., Best & Donovan Electrical Stunner, model ES in figure 2-1a). The lowest voltage and frequency over the domestic distribution networks is 110 VAC at 60 Hz in North America (Canada, United States) and 220 VAC at 50 Hz in Europe. 110 and 220-VAC domestic power sources are generally considered to be too weak to guarantee a minimum current flow of 1.3 ampere (EFSA standards). Table 2-2 suggests that the impedance between two electrodes, positioned as commonly done at the slaughterhouse, would be in the order of 150 to 300 ohms. Applying Ohm’s law suggests that current flow from a 110 VAC source (Canada, United States) would always be under one ampere (table 2-3).

The EFSA report recommends a minimum voltage of 240 VAC when using electricity to stun or kill swine, whether this is done in one or in two steps. According to Troeger et Woltersdorf (1989), the voltage required to obtain a current of 1.2 A is at least 250 VAC and is probably even higher when resistance between the two electrodes is 300 ohms or more (Table 2-3).

All of these recommendations are valid when using the equipment with standard positions (contact electrodes on the forehead or tongs on each side of the head) and apply to stunning swine for slaughter. However, these recommendations could be quite different with other types of connections and a procedure optimized for electrocution of swine.

Table 2-3. Theoretical variance of current flow between two electrodes with an increase in voltage from the alternating current source (current = voltage/impedance)

Impedance between electrodes	110 VAC	220 VAC	300 VAC	600 VAC
150 ohms	733 mA	1,466 mA	2,000 mA	4,000 mA
300 ohms	367 mA	733 mA	1,000 mA	2,000 mA
600 ohms	183 mA	366 mA	500 mA	1,000 mA

2.6.2.2 Current frequency (Hertz)

Increasing the frequency of the current from 60 to 12,000 Hz decreases the electrical impedance of the tissue (Figure 2-2). Consequently, it is possible to predict that, for the same voltage and the same electrode positions, the flow of current should increase with the frequency of the current. The studies of Lambooij *et al.*, (1996) realized with a current source of 250 volts and 800 Hz suggest this concept (Table 2-2).

Increasing the quantity of current by increasing its frequency does not necessarily mean an improvement in the effectiveness of the technique of stunning and/or electrocution. In fact, changing the frequency of the current may also change the current's path through the animal. The results of various research studies mentioned below suggest this concept.

Croft (1952), working with rabbits, swine and humans, studied the optimal frequencies to bring on loss of consciousness by electrical stunning. He recommends frequencies from 50 to 200 Hz and concludes that the standard European and American frequencies (50 Hz and 60 Hz) are suitable for electrical stunning. He mentions that a frequency of 25 Hz does not cause loss of consciousness.

Anil and McKinstry (1992) compared the effectiveness of current at a frequency of 50 Hz with current at a frequency of 1592 Hz or of 1642 Hz to stun 60 to 80 kg swine. They conclude that the high frequencies seem to be acceptable for the animal's well-being since they bring about a state of epilepsy and unconsciousness. However, they note that although the three tested frequencies are efficient, frequencies above 50 Hz bring on a quicker return to sensibility.

Anil and McKinstry (1992) report that Croft (1952), Borzuta (1971), Hlavinka (1978), Hoenderken (1978) and van der Wal (1978) all agree that using high frequencies to stun the animals for butchering does not bring satisfactory results relative to the animal's welfare.

Grandin (2003) mentions that stunning obtained by applying high frequencies to the head causes flailing of the legs, which may increase risk of accident for the operators. On the other hand, the legs stop flailing when the current passes through the heart and causes cardiac arrest. (Grandin, 2003)

Lambooij *et al.*, (1996) demonstrated that current at a frequency of 800 Hz (220 VAC) applied at the level of the brain, combined with current at 50 Hz (125 VAC) in the heart area is an effective method for stunning slaughter pigs.

Although changing the frequency allowed the operator to modify the characteristics of the electrical circuit, most commercial electrical stunners work with the frequency of the current in the domestic power grid (50 Hz in Europe and 60 Hz in North America – Table 2-1 and Table 2-2).

2.6.2.3 Wave forms

The results presented by Anil and McKinstry (1992) suggest that the wave form of alternating current can also influence the effectiveness of the electrical stunning of swine. Alternating current in the domestic power grid has the form of a sine wave. It is possible to change wave forms by using a variety of filters. The results presented by Anil and McKinstry (1992) show that the minimum interval for return of a response to a painful stimulus is 28 seconds for swine stunned by square waves and 36 seconds for swine stunned by sine waves.

2.6.2.4 Contact electrodes

The design of the contact electrodes may affect their effectiveness in stunning swine. Improvement in electrode design has made it possible to decrease resistance to contact and thus has increased the intensity of the electrical current (A) without a need to increase the voltage (V). The choice of good material in the manufacturing of the electrodes is important as well (Sparrey and Wotton, 1997).The material chosen must have good conductivity, good resistance to corrosion and be easy to clean. Copper is one of the best conductors but, weight for weight, aluminum is better. Stainless steel is very interesting because of its hygienic properties.

The various tongs and electrodes used for electrical stunning swine prior to slaughter have been described by Sparrey and Wotton (1997). The most common ones used for electrically stunning swine have an overall length of around 700 to 750 mm and a maximum opening of 300 mm (Figure 2-1). In general, rectangular or circular electrodes are attached solidly to the tongs. New models of electrodes now in use have a rectangular shape and rows of triangular points (Kentmaster or Abachem models), while another mode has a circular shape and a series of rounded points in the middle. A recent model from Stork RMS has only one sharp point in the centre. The point allows for better electrical contact because it penetrates the skin.

2.6.3 Current path

The path of electrical current through the animal is a determining factor in the physiological impact of electrification. A weaker current passing through a vital organ (e.g., heart, brain) will have greater effect on the animal than a stronger current running through a secondary organ (e.g., leg muscles). When the animal is electrified, the current flows between the two source poles finding the path which has the least resistance.

Pork is not a uniform conductor since it is made up of different tissues with specific resistances. Specific resistance (also called resistivity) of tissues, measured in ohms per centimetre (Ω/cm) is: 147 Ω/cm for blood; 222 Ω/cm for nerve tissue; 400 Ω/cm for muscle; 1,820 Ω/cm for bone and 2,222 Ω/cm for fat (Eike *et al.*, 2005). These measures of resistivity allow us to better understand the difference between the tissues but they do not allow us to predict the resistance between two electrodes placed on an animal at a known distance. The impedance between electrodes placed on either side of the head of a 60 – 80 kg pig (15-20 cm) is from 150 to 300 ohms at 50 Hz (Table 2-2).

When a current source is applied to an animal, the current takes the easiest path, meaning the path with least resistance. Understanding this principle of electricity has important implications for validating electrical stunning or electrocution techniques for swine. The following principles need to be kept in mind:

- there may be major difference in resistance between different positions of electrodes on the same animal. Information on the specific resistance suggests that positioning the electrodes on the mucous membrane will enhance the flow of the current more than placing it on the skin or in any area with a great amount of fat;
- the best place to position the electrodes designed to induce unconsciousness and kill the animal is a position which will maximize the flow of current in the vital tissue (e.g., the heart);
- an intuitive placing of the electrodes (on each side of the brain) is not necessarily the most effective position to induce unconsciousness and electrocute the animal since the current takes the easiest path and does not necessarily flow in a straight line between the two electrodes.

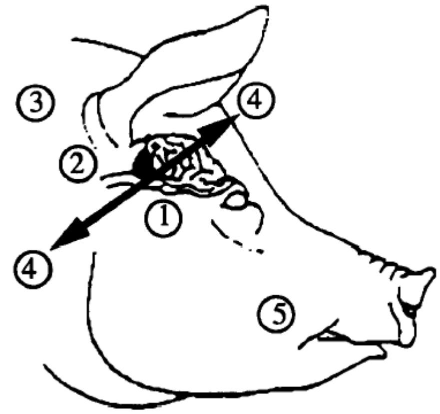
These principles demonstrate the necessity of confirming the effectiveness of different configuration of the electrodes on living animals.

2.6.3.1 Electrodes positions (tongs) on the head

Most of the electric stunners in slaughterhouses use tongs or contact electrodes as shown in figure 2-1. Generally, it is recommended to place the tongs on both sides of the brain to maximize the probability of reaching the neurones and of thus stunning the swine (Ministry of Agriculture, Fisheries and Food, 1995). Operators of electric stunners use different strategies which are explained by Anil *et al.*, 1997. The five principle positions are laid out in figure 2-3.

Sparrey and Wotton, 1997 consider that the positions least likely to maximize the flow of current to the brain (positions 3 and 5) are unacceptable. In their opinion, placing the tongs so that one electrode is beneath each ear (position 2) is the best possible position for optimizing the stunning of swine. These two regions come closest to being parallel to the head, thus optimizing the surface in contact with the tongs. Sparrey and Wotton postulate that the current crosses through the brain following the optic and auditory nerves. Another interesting position involves placing the electrodes between the ear and the eye on each side of the head (position 1), but these areas are slightly less parallel.

Figure 2-3. Tong positions as observed at the slaughterhouse.
The two tong electrodes touch: 1) an eye and the base of the opposite ear; 2) the base of one ear and the base of the other; 3) two sides of the neck; 4) the underside of the head and under the mandible; 5) both sides of the upper jaw.



Taken from Anil *et al.*, 1997

For swine in restraint or squeeze cages, a different position is usually used. It involves placing the electrodes diagonally under and on top of the head (position 4). Even if the path between the two electrodes is longer, Sparrey and Wotton, 1997 contend that the current will pass effectively through the brain all the same.

As described above, the position of the tongs significantly influences the strength of the current required to efficiently stun swine. This factor is generally not considered when various policy organisations set up their standards for electrical stunning. Thus, the minimum standard of 1.3 A for 1 second, cited by a number of guides, comes from the work of Hoenderken (1978), carried out with the electrodes placed on both sides of the neck behind the ears (position 3). Many studies suggest that weaker current (0.40 A) with the electrodes better placed (position 1 or 2 – figure 2-3) and with a longer duration (3 to 7 seconds) would allow effective stunning of swine. (Anil, 1991a; Anil and McKinstry, 1992; Hoenderken, 1978; McKinstry and Anil, 2004; Wotton *et al.*, 1992; Lambooij *et al.*, 1996).

2.6.3.2 Other electrode positions

Although most of the electrical stunners used in slaughterhouses are equipped with tongs or contact electrodes as shown in figure 2-1, other techniques have been described by researchers. For example, it is well-known that it is possible to electrocute swine by passing current from the mouth to the anus or from the head to the ground (Veenhuizen, 1994, AVMA, 2001). Members of a panel of the American Veterinary Medical Association (AVMA) consider that techniques where the electrical current is applied head-to-tail, head-to-foot or from the head to a metal plaque where the animal is standing, are unacceptable (AVMA, 2001).

2.7 Devices for electrocuting swine

To our knowledge, there exists no commercially-available device specifically developed for on-farm electrocution of compromised swine. Such a device would have to respect requirements concerning the well-being of the swine, the process would have to be socially acceptable and safe for workers. As well, all of this would have to be available at a reasonable cost. Most of the official guides recommend electrical stunners developed for slaughterhouses. Of course, it is also well-known that many pork producers have developed « home-made » techniques for electrocuting swine.

The American brochure, « On farm euthanasia of swine options for the producer » (AASV and NPPC, 1997), recommends using a commercial pig stunner to electrocute the animals. This equipment is costly (from $3,750 to $7,650), (Chevillon, 2005) and potentially dangerous (300 to 500 VAC), which hinders its use on the farm. The same brochure restates the recommendations for slaughterhouses: application of a source current of 300 VAC to the animal's head for one second in order to obtain a minimum current of 1.25 A.

Many pork producers in Quebec use a cobbled together electrocution technique whose main element is automobile booster cables (also called « jumper cables »). These producers adapt a 110 VAC electrical outlet to accept one end of the booster cable and they retain the clamp on the other end. The booster cable clamp is usually attached to an ear and the base of the tail to bring about electrocution in one step (Denicourt *et al.*, 2006). The technology is not standardised and is unsafe.

3 Hypothesis and goals

3.1 Hypothesis

It is possible to electrocute swine in a humane way in only one step using a domestic 110 or 220 VAC power source.

3.2 Overall goal

Develop an on-farm, turnkey method of euthanasia by electrocution for compromised swine that respects the requirements concerning the well-being of the animals, is socially acceptable and safe for workers, at an affordable price

3.3 Specific objectives

- Identify the electrodes and the best contact points which minimize the impedance and maximize the chances of electrocuting the swine;
- Estimate the average value and the natural variability of impedance in compromised swine in different weight categories (<5, 5-24, 24-50, 50-80 and >80 kg) between the best contact points;
- For each weight category, measure the flow of current between the points of contact under 110 and/or 220 voltage;
- Confirm the effectiveness of the selected method of electrocution on non-anaesthetized swine;
- Develop and define the characteristics of material required to electrocute swine (transformer, clamps, cables, squeeze cages, etc.) keeping in mind animal well-being, worker safety and cost;
- Ensure that the method is socially acceptable from the point of view of animal well-being;
- Produce a written guide and prepare a training program which will complete the information already available (FPPQ technical information sheet on on-farm euthanizing of swine and training).

4 Work Plan

4.1 Developing the technology

The technique for euthanizing by electrocution was developed in four phases. The first three development phases were carried out by a multi-disciplinary team from the CDPQ and the FMV with high-precision commercial instruments: multimeters, function generators, electroencephalograph (EEG), electrocardiograph (ECG) and by equipment specially designed for the project (transformer, electrocuter, safety equipment, etc.). Trials were carried out at the Faculty of Veterinary Medicine's Frontenac Farm in Saint-Hyacinthe, Quebec. The protocol had been previously accepted by the ethics committee on animal use of the University of Montreal (06-Rech-1225).

The first phase involved estimating the impedance with a low-voltage power source (6 VAC, 600 Hz) at different contact points (electrode positions) and with various kinds of electrodes (clamps, belts, cables, etc).

The second phase was concerned with comparing the effectiveness of the electrocution procedure using the two selected configurations with the results from phase 1. The selected configurations had to minimize the impedance between the two contact electrodes, maximize the probability of a successful electrocution, be easy to use and be visually acceptable. The first and second phases were carried out on anaesthetized swine.

The third phase consisted in confirming the selected method from the preceding phase on 21 living, non-anaesthetized swine.

Development of commercial-style equipment for electrocuting the swine (phase 4) was assigned to the equipment manufacturer Conception Ro-Main.

Lastly, a technique for electrical stunning (head only) was evaluated using a small number of swine (n=10) in order to compare observed clinical signs during electrical stunning with those observed during electrocution.

The final technology was confirmed for swine from 5 to 125 kg. A small number of piglets less that 5 kg were euthanized by electrocution as well, but the technology described in this project was not necessarily optimized for piglets.

4.2 Publication of results and confirmation of the technology

The results obtained during the project were presented at various forums (Appendix A). As well, the technology was presented to two animal welfare committees to confirm that the procedure was socially acceptable. (Appendix B and C).

5 Material and method

5.1 Animals

We used a total of 113 commercial pigs, compromised in various ways or simply rejected for sale because of insufficient weight. The pigs came from eleven commercial farms. The weights recorded ranged from 2.22 to 105 kg. They were put in five weight categories: $x < 5$ kg, $5 \leq x < 24$ kg, $24 \leq x < 50$ kg, $50 \leq x < 80$ kg and $x \geq 80$ kg, thus representing the various phases of Quebec pork production (Table 5-1). Their body condition, state of hydration and fragility status were assessed. The electrocution technique developed in this project has been validated for 5-105 kg pigs (91 pigs in these weight categories).

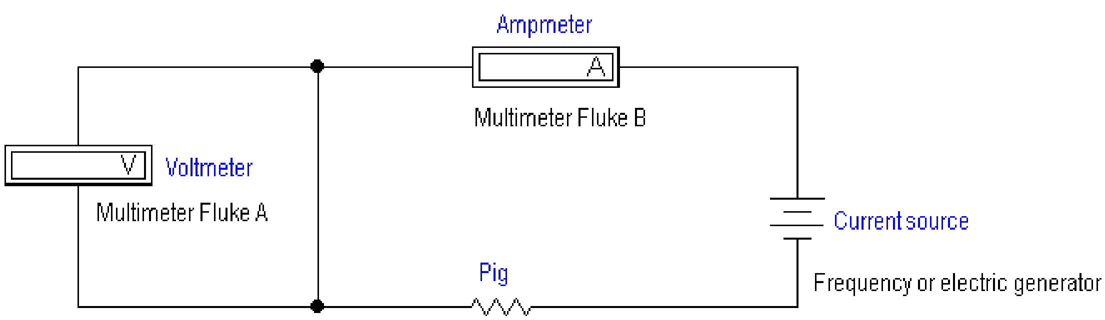
Table 5-1. Number of animals in each weight category

Weight category (kg)	Number of animals
<5	22
5-24	37
24-50	26
50-80	17
>=80	11
Total	113

5.2 Equipment and electrical measurement

As the technique was being developed (phases 1 to 3), the current (A), the voltage (V) and the frequency (Hz) were measured throughout the duration of the electrification (Figure 5-1).

Figure 5-1. Schematic description of the installation. The voltmeter measured the voltage and the frequency of the current. The ampmeter measured the flow.



The strength, voltage and frequency were measured using two tabletop multimeters[3] (Figure 5-2). The first multimeter measured the voltage and the frequency of the power source and the second multimeter measured the current. By recording the voltage and the flow, it was possible to calculate the impedance between the electrodes using Ohm's law (impedance = voltage/current).

Figure 5-2. Multimeters at work

An electric generator[4] and various types of safety equipment were designed especially for this project by an engineering firm (Figure 5-3). The electric generator is designed to produce a 110 or 220 VAC power independent of the domestic power grid. This technical specification permits to prevent current leakage to the ground during electrocution. Some accessories were added such as a programmable timer, illuminated displays and a system with two push buttons for the power-on process. One button lets the user select the voltage (110 or 220 VAC) and the other lets him or her select the duration. Three options are available: 3, 5 and 15 seconds. These specific technical parameters make it possible to increase both the flexibility and the safety of the equipment.

Figure 5-3. Electric generator

[3] Fluke®, modèle 45, Montréal, QC, Canada
[4] Benoit Baillargeon inc., Sainte-Marie, Qc, Canada

The current required for evaluating impedance at low voltage (6 VCA; 60, 600, 6,000 Hz) was produced by a wave generator[5] (Figure 5-4). The generator permits to vary the frequency (0.2 Hz-2 MHz), the voltage (0-10 VCA) and the wave form (sine, square and triangle).

Figure 5-4. Frequency generator

5.3 Collecting and processing electrification data

The two multimeters calculated and transferred the measurements of current (multimeter #1), voltage (multimeter #2) and frequency (multimeter #2) in real time to the computer's Access database. The precision and the specifications of the multimeters are set out in Appendix D.

The method of recording the data was different for electrification at 6 volts as compared to electrification at 110 and 220 volts. Three operational modes were defined to describe the electrifications. These operational modes were applied mainly to live pig but, on occasion, to dead pig as well.

Impedance mode: this mode described the procedure for electrification at low voltage (6 VAC). The goal of electrification mode was to obtain a value for measuring impedance. Electrification in « Impedance mode » was carried out mainly on live pig but, on occasion, on dead pig as well.

Euthanasia mode: This mode described the electrification procedures under residential or domestic voltage (110 or 220 VAC). The goal of this electrification mode was mostly to euthanize the pig. In « Euthanasia mode », the electrodes were applied to the animal to run the current from the head to the area behind the heart. Electrification in « Euthanasia mode » was carried out mainly on live pig but, on occasion, on dead pig as well.

Stunning mode: This mode described electrification procedures under residential or domestic voltage (110 or 220 VAC). The goal of this electrification mode was basically to stun the pig. The electrodes were applied across the animal's head. Electrification under domestic voltages in « Stunning mode » was carried out solely on live pig.

5 Wavetech®, model FG2A, Montréal, Qc, Canada

For low voltage electrification in « Impedance » mode, the operator began electrifying the pig before starting to record measurements in the Access data base. In this situation, the duration of the electrification was always longer than the duration of the recording. Moreover, the operator waited until both measurement instruments returned constant and stable results before beginning to record to the Access database. In low-voltage electrification (6 VAC), both multimeters transferred the data to the Access database infrequently (< 3 readings per second). The first meter simultaneously calculated the voltage and the frequency (~ 0.5 reading/s) and the second meter measured current at the highest possible resolution (~ 2.5 readings/s).

For electrification under domestic tension in « Euthanasia » and « Stunning » modes, the operator started and stopped recording the data to the Access database a few seconds before and after the electrification. In this situation, the data recording always took a little longer than the duration of the electrification. In electrification under domestic voltage, both multimeters calculated and transferred the data at the weakest resolution in order to maximize the reading speed (> 15 readings/s) when current was present (Appendix D).

After data collection, the database contained various kinds of data:

- Readings recorded at the right time (> 90% of the data);
- Readings recorded prior to and after electrification of pig using domestic current;
- Readings recorded when no piglets were attached;
- Readings recorded when the instruments were not properly adjusted.

Each series of readings corresponding to an electrification was identified by a unique identifier. An electrification was characterized by type of connection, voltage, frequency and by the status of the pig (dead or alive). The data were processed in order to produce a valid database (labelled DATAEUTH) for the analyses (Appendix E).

5.4 Duration and voltage during electrocution

Most of the electrocutions were carried out with a source current of 110 VAC over a period of 5 seconds. Some electrocutions were carried out with higher voltage and shorter (3 s) or longer (15 s) durations.

5.5 Characteristics of the effects of electrification with domestic voltage

Immediately following each electrification under domestic voltage (110 or 220 VAC), the following observations were recorded to evaluate unconsciousness in mode « stunning » and the animal's death in mode « euthanasia »: presence of mydriasis (dilation of the pupil), absence of corneal reflex, absence of nociception (response to a pin or needle prick), disappearance of breathing reflex, cardiac fibrillation (ECG) and disappearance of electric brain activity (EEG). We also noted the following observations: presence of agonal gasps, loss of sphincter control (anal and/or urinary). Lastly, all of the electrifications under domestic voltage were filmed with a digital camcorder[6] so that we could evaluate the motor activity during and after electrification.

5.5.1 Evaluation of motor activity

Two patterns of behaviour were identified based on video images: the pattern of behaviour when put to death by electrocution (« euthanasia » mode) and the pattern of behaviour during electrical stunning (« stunning » mode).

During a successful electrocution, the following motor activities may be observed: tonic phase (during and after electrocution), collapse of the animal, a phase of muscular trembling with gradual loss of tone in all of the muscles building to an irreversible flaccid phase. In some cases, gasps were observed.

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[6] Panasonic®, model PV-GS59, Montréal, Qc, Canada

The characteristics of the following motor activities were evaluated and recorded in a database.

- **Length of the tonic phase (in seconds)** including the electrocution time;
- **Length of the trembling phase (in seconds)**[7], length of time between the end of the tonic phase and the complete flaccidity of the animal. It is conventionally understood that the length of the trembling phase is considered as equal to zero second when the collapse of the animal occurs before the end of the electrocution;
- **Presence of gasps (Yes or No).** Observation of one or more agonal gasps was recorded in the database. Analysis of the video recordings permitted to characterize the gasps of most of the pigs;
- **Muscle tremors (Yes or No);**
- **Leg movement (Yes or No).** Presence of leg movement. A leg movement indicates less than three movements (extension or contraction) of one or more legs;
- **Paddling (Yes or No).** Paddling is defined as a sequence of more than three movements in one or several of the animal's limbs;
- **Length of time between the end of the electrocution and the first gasp (in seconds);**
- **Number of gasps (n).** Number of gasps between the end of the tonic phase and stopping the video (5 to 6 minutes after the electrocution);
- **Length of time between the first and the last gasp (in seconds).**

During electrical stunning, epileptiform motor activities may be observed: tonic phase (during and after electrocution), clonic phase (convulsions, paddling and muscle trembling), return to consciousness phase. The following characteristics of motor activity were recorded:

- **Length of the tonic phase (in seconds)** including the period of electrocution;
- **Length of the clonic phase (in seconds),** length of time between the end of the tonic phase and wake-up. The wake-up is characterized by a return to regular breathing;
- **Muscle tremors (Yes or No)**;
- **Leg movement (Yes or No).** Presence of leg movement. A leg movement indicates less than three movements (extension or contraction) of one or more legs;
- **Paddling (Yes or No).** Paddling is defined as a sequence of more than three movements in one or several of the animal's limbs.

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[7] The project's authors hesitated in finding the precise term permitting to describe observed global motor activities between the end of the tonic phase and the complete flaccidity of the animal. The term used should make it possible to: 1) to do a good description of observations; 2) describe the motor activities of most pigs with 5 and 15 s electrocution durations; 3) to distinguish with the motor activities observed between the tonic phase and the return to consciousness in stunning mode. Three terminologies were discussed and used in the preliminary publications and presentations: 1) intermediate phase; 2) light clonic phase; 3) trembling phase. Finally, the term "trembling phase" was selected.

5.5.2 Encephalogram and electrocardiogram

Brain and heart activities were recorded before and immediately after electrification (stunning mode) or electrocution (euthanasia mode) with an electroencephalograph (EEG)[8] and an electrocardiograph (ECG). The measurements were recorded in an integrated database[9]. Readings were taken using cup electrodes applied directly to the shaved skin in the designated areas (cardiac and forehead areas). A conductivity gel was inserted in the cup to improve contact between the electrode and the skin. Recording began a couple of seconds before electrification and continued until the animal was brain dead. The equipment was powered on throughout the electrification; however, the recordings were distorted by the effect of a built-in filter which blocked the 60 Hz frequency.

5.6 Evaluating unconsciousness

The following indicators were used to confirm the unconsciousness state of the animal: mydriasis, absence of corneal, nociceptive and respiratory reflexes.

5.7 Evaluating the death of the animal

The death of the animal was confirmed by its collapse by cardiac fibrillation (ECG), by the absence of corneal, nociceptive and respiratory reflexes, and by an isoelectric EEG.

5.8 Electrodes and contact points

A large number of electrodes and contact points were tested in order to identify the most promising connections for electrocuting pig (Table 5-2). A connection represented two or three contact points with different types of electrodes. The connections we chose had to respect the following criteria:

- maximize the contact surface;
- minimize trauma.

[8] Alliance portable system, Nicolet Biomedical Inc, Memphis, TN, USA Intuition EEG software
[9] Nic Vue™

Table 5-2. Code and description of the various electrodes and contact points

Électrode	Connection		Description
RED	2PCBO		1 hook clip at the base of each ear
	2PPBO		1 flat nose clip at the base of each ear
	A1Q		Nº 1 alligator clip at the base of the tail
	BRAC		Braided metal belt around the neck
	CHMS/CMC		Small chain around upper jaw and braided metal belt around the neck
	Lasso	F1/8	1/8 inch wire around upper jaw
		F3/16	3/16 inch wire around upper jaw
	LAS/CMC		1/8 inch wire around the upper jaw and braided metal belt on the neck
	PCBO		1 hook clip at the base of one ear
	PCGO		1 hook clip at the edge of the mouth and another at the base of the left ear
	PCGU		1 hook clip at the edge of the mouth
	PPBO		1 flat nose clip at the base of an ear
	PPGO		1 flat nose clip at the edge of the mouth and at the base of the left ear
	PPGU		1 flat nose clip at the edge of the mouth
BLACK	CAB		Small chain around the abdomen
	CHAB		Chain around the abdomen
	CHOKER		Mid-size dog collar, length 56 cm
	CMTA		Braided metal belt around the abdomen
	PCQ		Hook clip around tail
	PPAI		Flat nose clip at the groin fold
	PPBQ		Flat nose clip at the base of the tail
	PPQ		Flat nose clip at the tail
	Rectal	RESOR	Spring in the rectum with a metal washer at the end
		STOPA	Door stopper in the rectum
		GPapillon	Large wing screw
		PPapillon	Small wing screw

The selected contact points were: the base of the ear (1 ear or 2 ears), the edge of the mouth, the upper jaw, the neck, the abdomen, the groin, the tail, the anus, the leg.

The selected electrode types were: various kinds of clips, four kinds of rectal probes (door stop, spring, small and large wing screw), various kinds of chains and cables (Table 5-2 and Figure 5-5).

Figure 5-5. Description of the main electrodes


Alligator clips nº 1


Braided metal belt


Hook clip


Door stopper


Flat nosed clamp


1/8-inch cable

It was quickly apparent that a number of connections were inadequate and impractical. The main connections chosen for systematic evaluation are listed in table 5-3.

Table 5-3. List of the main connections that were tested (n>10) and their number of repetitions

Front connection	F3/16	F3/16	F3/16	F3/16	F3/16	F3/16	F3/16	F3/16	PPBO
Rear connection	RESOR	CMTA-S	CAB	PPAI	PPBQ	PPQ	STOPA	CHAB	PPBQ
Number	47	22	20	18	15	14	14	11	10

5.9 Animal restraint

A restraint cage (squeeze cage) was developed to let operators confirm the selected methods of euthanasia on non-anaesthetized pigs. The restraint cage was designed to keep the animal still and ensure operator safety (Figure 5-6).

Figure 5-6. Squeeze cage

5.10 Data management

5.10.1 Database

All of the measurements carried out for this project were recorded in four independent databases: 1) a file which contained all of the confirmed characteristics of electrification (DATAEUTH); 2) a file which contained all the characteristics of the pig (DATAPORC); 3) a file which contained all of the characteristics obtained from the videos (DATAVIDEO) and 4) a file that served as a data dashboard for managing the data (TABBORD). Processing this data has allowed us to create the various data groupings necessary for statistical analysis.

5.10.2 Weight categories

The pigs were divided into five weight categories: $x < 5$ kg, $5 \geq x < 24$ kg, $24 \leq x < 50$ kg, $50 \leq x < 80$ kg and $x \geq 80$ kg, representing the different phases of pork production in Quebec (table 5-1).

5.10.3 Connection categories

Some connections were grouped into a new variable. The main groups are:

- All of the connections having various gauge steel wires on the upper jaw (1/8", 3/32", 5/32" and 3/16" wires) were grouped together under a new variable called « Lasso ». This category was justified by the fact that the length of the steel wires was adjusted to the size of the pig's jaw;
- All of the connections with various kinds of rectal probes (spring, door stop, large wing screw and small wing screw) were grouped together under a new variable called « Rectal ».

5.10.4 Categories of animal consciousness

During all of the handling, living animals were either anaesthetized, sedated or without psychoactive drugs (Appendix F). These three modes were classed under a new variable using the names « ANES », « TRAN » and « NONA » to describe, respectively, the three states of consciousness.

5.10.5 Categories of frequency

The adjustment of the frequency of the generator's alternating current in mode « impedance » to 6 VAC was approximate (± 10%). Current frequency was classed under the following nominal values:

- 60 Hz for all measurements between 55 and 66 Hz;
- 500 Hz for all measurements between 480 and 520 Hz;
- 600 Hz for all measurements between 570 and 630 Hz;
- 6,000 Hz for all measurements between 5,700 and 6,300 Hz;
- 60,000 Hz for all measurements between 57,000 and 63,000 Hz.

All other measurements carried out at 6 volts using other frequencies were eliminated.

The frequency of all of the measurements carried out using domestic current (110 and 220 VAC) was fixed at 60 Hz. A number of checks of the frequency of the domestic network confirmed that this characteristic was stable.

5.10.6 Categories of electrification

Electrifications were carried out at different voltages (6, 110 and 220 VCA), at different frequencies (60, 500, 600, 6,000 and 60,000 Hz) and on pigs with distinct states of consciousness (ANES, TRAN, NONA and MORT). A total of 28 categories of electrification was created under a new variable.

5.11 Statistical tests

Descriptive statistics (average, standard deviation, min., max.) were calculated to describe the characteristics of the various electrifications for pigs in various weight categories. The effect of the pig weight and their body condition on impedance was also checked. Some Pearson correlations were calculated to describe the strength of associations. We set the level of statistical significance at 5% ($P < 0.05$).

Some measurements were carried out on piglets (< 5 kg) but the electrocution technique has not been confirmed for this kind of pigs. The goal of the project was to confirm a technique of electrocution for pigs from 5 to 110 kg.

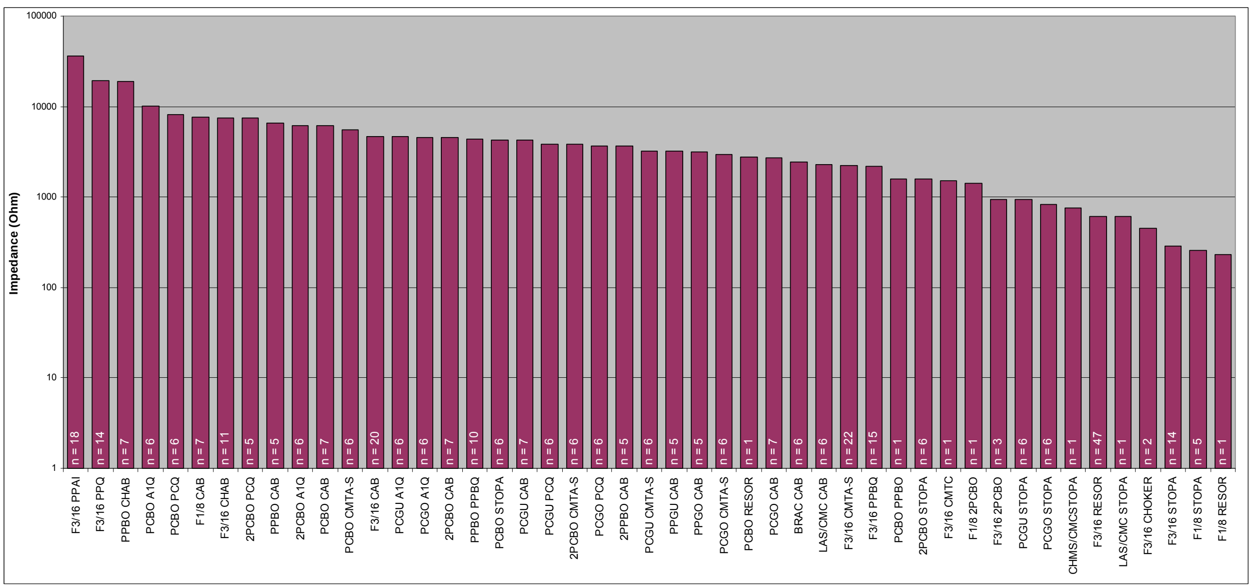
6 Results and discussion

The experiments carried out for the project once again underlined the importance of the position and of the type of electrodes when euthanizing pigs by electrocution. For example, with some configurations of electrodes, current of around 3 amperes would not stun or kill the pigs. Both of our selected methodologies (5 seconds at 110 VAC) enabled repeated, rapid killing of animals with various weights (over 100 animals weighing from 5 to 125 kg were killed within 5 to 6 seconds each), with considerably less current (~ 1 A).

6.1 Selecting electrodes and contact points (6 V)

The type of electrodes and their placement have a very significant impact on impedance (max. 35,847 Ω, min. 233 Ω, $P < 0.0001$) and, consequently on the amount of current that flows through the pig during the electrocution process (Figure 6-1).

Figure 6-1. Impedance measured at low voltage (6 V) with various connections (type of electrode and position)



The connection on the upper jaw with a cable (F3/16) was both the worst and the best of connections. Clips on the ear tips (PCBO), clips in the fold of the groin (PPAI) and clips on the tail (PPQ) were often among the worst. The connections (ear-to-tail or ear-to-fold of groin) are the most used by pork producers to electrocute animals with the jumper cable technique. The results of this study show that it is possible to greatly improve on-farm techniques simply by choosing better contact points. In this first phase, connections to the mucous membranes (cables on the upper jaw and rectal probes) make for the best conductivity (least impedance).

6.2 Selected electrocution techniques

The techniques selected had to make it possible to run a maximum current through the animal (weak impedance) with the least possible trauma. Two techniques were selected:

- anal probe combined with a steel lasso attached to the upper jaw (SA-LA method, Figure 6-2);
- metal belt around the abdomen combined with the lasso around the upper jaw (CM-LA method, Figure 6-3).

Figure 6-2. Lasso-anal probe

Figure 6-3. Lasso-Metal belt

Two methods were compared by electrocuting 37 pigs using the SA-LA method and 21 pigs using the CM-LA method. Electrocution of all of the pigs was carried out using a 110 VAC power source at 60 Hz for a duration of 5 seconds. The current measured between the electrodes (mean ± std) with the Lasso-rectal and Lasso-belt techniques was, respectively, 0.94 ± 0.15 A and 1.00 ± 0.19 A ($P > 0.05$).

It is interesting to note how similar the measurements are, using these two techniques given that the Lasso-belt connection appeared less interesting at 6 VAC (Table 6-1).

This difference may be explained by a tighter contact of the belt in euthanasia mode than in impedance mode. In fact, when low voltage impedance (6 VAC) was measured, the anaesthetized pigs were lying down on a rubber mat on the ground with a belt around their abdomen while during the euthanasia (110 VAC), the animals were standing, slightly suspended by the belt (Figure 6-3).

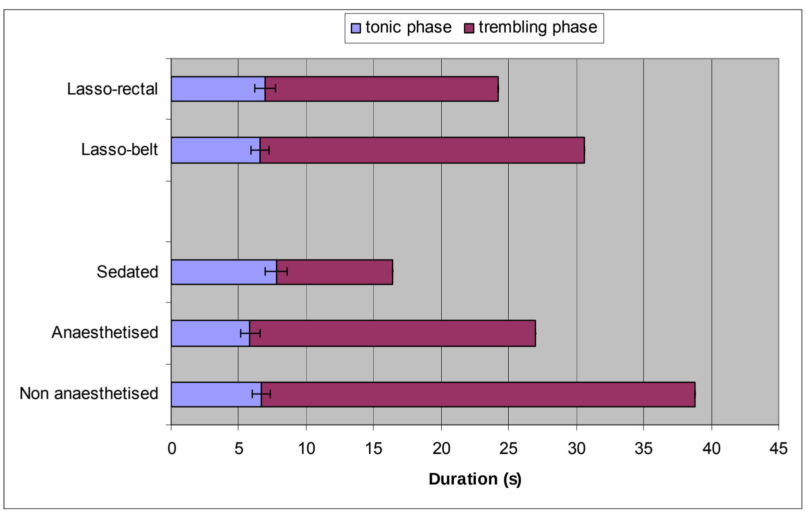
Table 6-1. Impedance (Ω) at low voltage (6 VCA)

Weight (kg)	1st position	2nd position	3rd position	4th position	5th position	6th position
5-24	Spring-F3/16 451 Ω	PPBQ-F3/16 1,527 Ω	PPQ-F3/16 5,635 Ω	CAB-F3/16 6,593 Ω	PPAI-F3/16 8,350 Ω	CMTA-F3/16 8,884 Ω
24-50	Spring-F3/16 312 Ω	PPQ-F3/16 820 Ω	CMTA-F3/16 2,711 Ω	PPBQ-F3/16 3,127 Ω	CAB-F3/16 4,426 Ω	PPAI-F3/16 5,576 Ω
50-80	Spring-F3/16 232 Ω	CMTA-F3/16 1,374 Ω	PPBQ-F3/16 1,582 Ω	PPQ-F3/16 1,741 Ω	CAB-F3/16 2,434 Ω	PPAI-F3/16 7,024 Ω
80 +	Spring-F3/16 242 Ω	PPBQ-F3/16 1,029 Ω	CMTA-F3/16 1,568 Ω	PPQ-F3/16 3,987 Ω	CAB-F3/16 4,494 Ω	PPAI-F3/16 14,649 Ω

6.3 Behavioural evaluation of the two selected electrocution techniques (110 V, 5 s)

Following the electrocution, the various phases indicating the death of the animal appeared. Typically, the pigs were in tonic phase during the whole period of the electrocution (110 V, 5 s). The tonic phase could extend for few seconds after the current was shut off (average 2.2 s; Figure 6-4)

Figure 6-4. Duration of the tonic and trembling phases during and after electrocution, depending on the connection used or on the status of the animal



After the current was shut off, all pigs had dilated pupils and no corneal, nociceptive or respiratory reflexes. And all had been in cardiac fibrillation. Two pigs euthanized with the Lasso-belt connection emitted vocalizations after the current had been cut off. One pig had dilated pupils and the other‘s eyes were rolled back. Both pigs emitted agonal gasps, indicating that the electrocution had been successful and that their hearts were in cardiac fibrillation.

Immediately following the tonic phase, pigs which had been standing during the electrocution collapsed and went completely flaccid. For most of the pigs, some trembling (ears, tails, various muscles) could be observed before the animal went completely limp. Lastly, for some pigs, we noticed slight leg movement, but no paddling. The trembling phase lasted, on average, 8, 21, and 32 seconds respectively for pigs that were anaesthetized, sedated and pigs that were not drugged (table 6-2 and figure 6-4).

Table 6-2. Average duration of the tonic and trembling phases

	Duration (s)	
Status	Tonic phase	Trembling phase
Anaesthetized	5.85	21.13[a]
Non anaesthetized	6.68	32.14[b]
Sedated	7.78	8.64[a]
Connection		
Lasso-belt	6.57	24.07
Lasso-rectal	6.97	17.20

The behaviour of the pig during electrocution shows some similarity with observations reported during the stunning by electrification (a tonic phase and some signs from the clonic phase) but the electrocuted pig showed no signs of an epileptiform seizure. Indeed, there is no breathing return, neither there is consciousness return with an efficient pig electrocution (see section 8.2).

The status (anaesthetized, non-anaesthetized or sedated; $P > 0.1$) as well as the type of connection ($P > 0.1$) did not have a significant effect on the duration of the tonic phase, which lasted from one to three more seconds after current flow through the animal had been stopped.

The duration of the trembling phase appeared to be slightly longer with the Lasso-belt connection than with the Lasso-rectal, but this difference was not significant (Table 6-2). On the other hand, the duration of the trembling phase was significantly longer with pigs which had received no psychoactive drug ($P < 0.0001$) compared to pigs that had been anaesthetized or sedated. Moreover, the digital data suggest that the trembling phase could be shorter in sedated pigs compared to anaesthetized pigs, but this difference is not significant (Table 6-2)

The main signs observed during the trembling phase were slight muscle trembling (63% of pigs) and gasps (46% of pigs) (Table 6-3). As well, there were some animals (< 10%) whose legs moved, but this did not resemble paddling. A summary analysis of the data suggests that the anaesthetized pigs (Table 6-4) and the pigs with the Lasso-rectal connection (Table 6-3) show more signs of myoclonia. The data for this project do not make it possible to elaborate the role of these two factors since almost all of the pigs electrocuted using the lasso-rectal technique were anaesthetized.

Table 6-3. Presence of visual criteria during trembling according to connection (% of pigs)

Combination	Myoclonia	Gasps	Leg movement
Lasso-rectal (n=33)	25	19	2
Lasso-belt (n=21)	9	6	3
Total (n=54)	34 (63.0%)	25 (46.3%)	5 (9.3%)

Frequency of occurrence of gasps was twice as high in pigs euthanized with the lasso-rectal connection. More than half the anaesthetized animals and those having received no psychoactive drugs showed gasps. On the other hand, there was only one animal, previously sedated with Stresnil® (azaperone), which gasped. Gasps lasted for an average length of 1 minute 15 seconds with a maximum of 5 minutes in the case of one particular pig. It should be noted that, at 6 VAC, impedance was measured several times on anaesthetized pigs prior to euthanizing them. Thus, at the time of euthanasia, the effect that anaesthetics could still have on the pigs was not all that important.

Table 6-4. Myoclonia, gasp and leg movement during the trembling phase (% of pigs) according to the status of the animal

Status	Myoclonia	Gasp	Leg movement
Anesthetized (n=29)	22	15	0
Sedated (n=9)	4	1	0
None (n=16)	8	9	5
Total (n=54)	34 (63.0%)	25 (46.3%)	5 (9.3%)

To sum up, gasps may be seen often and may last for several minutes. Some of this study's data suggest that using azaperone as a sedative would make it possible to reduce the number of pigs showing gasps after electrocution. This medication is recognized for its ability to block nerve transmissions. Nevertheless, using azaperone is not very useful since it leads to increased difficulty manipulating the animal and increases cost. As well, even though some people may find the phenomenon disagreeable, gasps occur after the animal is dead.

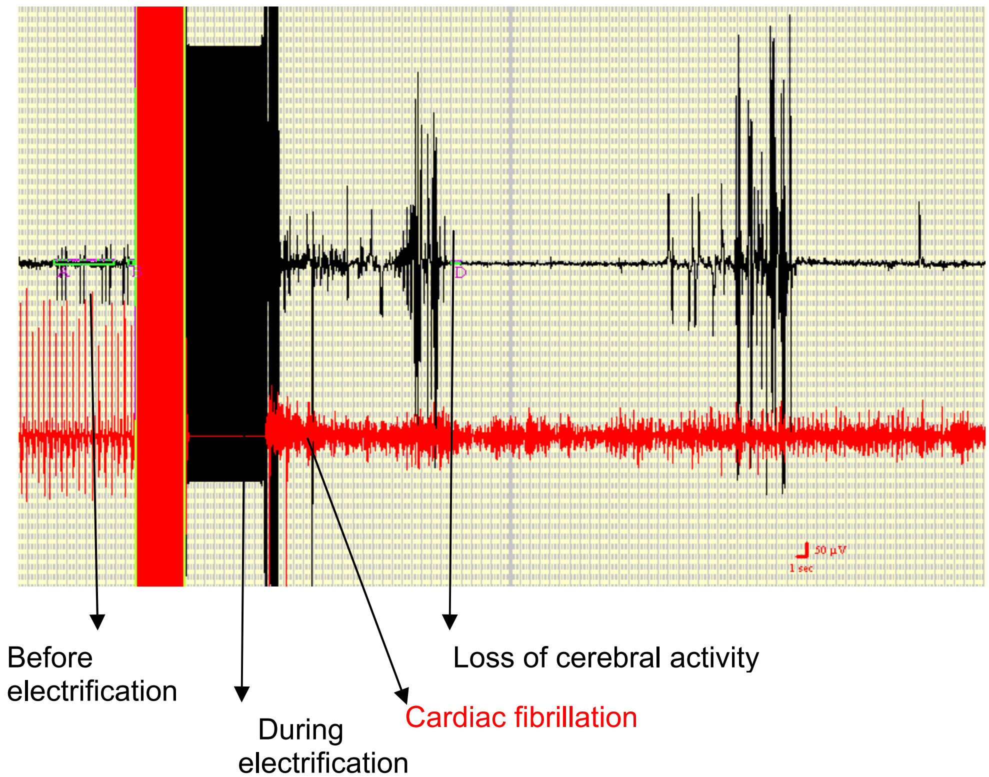
6.4 Evaluation of brain (EEG) and heart (ECG) activity

It was possible to measure brain (EEG) and heart (ECG) activity before and several seconds after the electrocution. The measurements were hard to interpret while the pigs were being electrocuted because they were blurred (Figure 6-5).

As soon as the recording became readable again, typical signs of cardiac fibrillation appeared. Brain activity was more difficult to interpret because testing of the animal's sensibility (corneal reflexes, nociception, etc.) carried out as soon as the current stopped, and the movement brought on by the gasps created interference that appeared on the EEG. After electrocution, the majority of the pigs quickly (< 1 s) showed a weak amplitude line that is usually associated with brain death. For now, no statistics have been carried out to characterize these EEGs. The data were recorded and analysis may be possible at a later date.

Recording the heart and brain activity made it possible to confirm the animal's death (cardiac fibrillation and isoelectric EEG). However, taking into account the interference during the electrocution, a few seconds were needed after the end of the electrification before adequately interpreting the readings in the graph. In short, the heart and brain activity formed an excellent complement to visual observation of behaviour.

Figure 6-5. Measurement of brain (black) and heart (red) activity

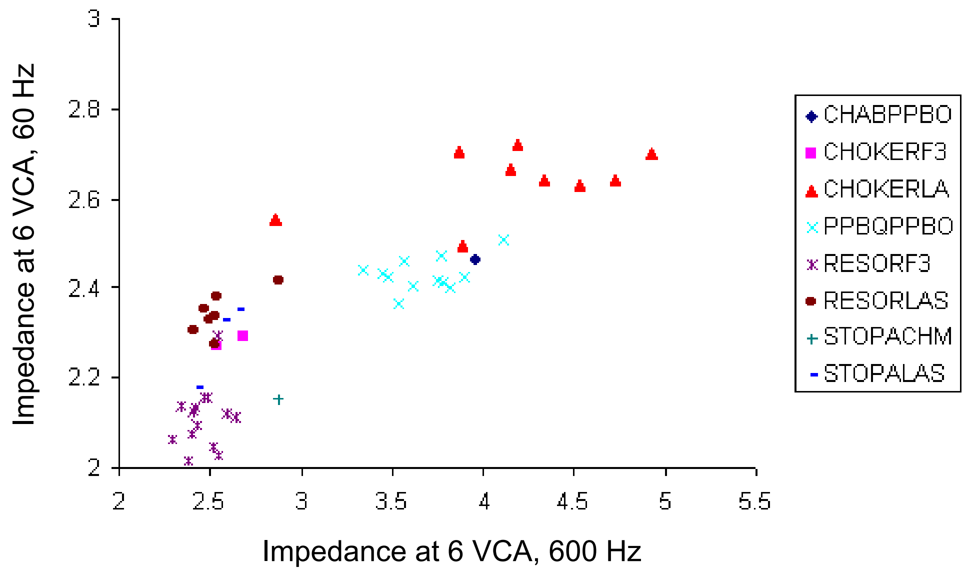


6.5 Low voltage impedance (6 VAC) and domestic power (110 and 220 VAC)

Electrical characteristics recorded during the electrocution of 49 pigs make it possible to confirm the relation between 6 VAC and the 110 VAC measurements. In order to do so, 24 pigs were euthanized with poorer connections (CHABPPBO, CHOKERF3, PPBQPPBO) and compared to the results obtained on 25 pigs with better connections (RESORF316, RESORLASSSO, STOPACHM, STOPALAS). These methods allowed us some latitude in estimating the impedance at 6 volts while still allowing for effective euthanasia at 110 VAC.

There is a positive and significant straight line relation ($P < 0.0001$) between the values for impedance measured during euthanasia (110 VAC) and those measured during the evaluation of the low voltage impedance (6 VAC) (Figure 6-6). Around 72% of the variation in impedance under domestic power (110 VAC) may be explained by the variation of the low-voltage impedance (6 VAC) (Figure 6-6), but the figure shows that the correlation is not perfect. As well, one has to note the important difference between the averages of the two estimates: 194 Ω compared to 933 Ω (value of 2.29 compared to 2.97 [log base 10]) for the estimate at 110 and 6 VAC respectively.

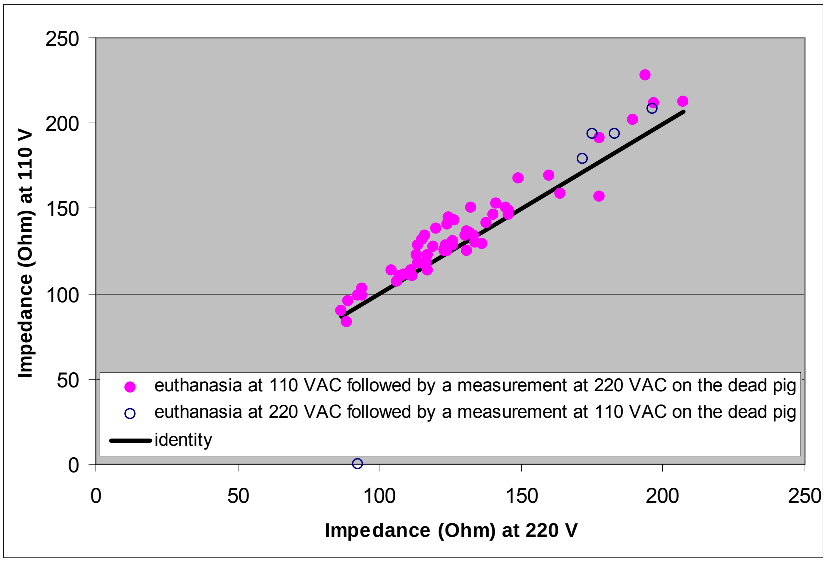
Figure 6-6. Relation between low-voltage impedance values (6 VCA, 600 Hz) and domestic power (110 VAC, 60 Hz) (value in log base 10)



The results of this project suggest that measurements of impedance taken at low voltage (6 VAC) on unconscious animals make it possible to judge the potential effectiveness at higher tension (110 VAC). However for unexplained reasons, the correlation is not perfect and the estimate of impedance at 6 VAC is considerably higher than that obtained at 110 VAC.

Measurements carried out immediately after the animal's death with alternating current (euthanasia at 110 VAC followed by a measurement at 220 VAC on the dead pig, or vice versa) and the same connection show that there is a close correlation between the two estimates (r=0.96; Figure 6-7) Moreover, one must take note of the very slight difference between the two averages (139 Ω at 110 VAC compared to 132 Ω at 220 VAC, $P < 0.001$). This difference might be explained by the voltage (220 VAC compared to 110 VAC) or perhaps by the status of the animals (live compared to dead). Data from this study do not permit to attribute this slight difference to one or the other of the factors since they were confounded (the majority of readings at 110 VAC on live pigs and the majority of readings at 220 VAC on dead pigs).

Figure 6-7. Relation between impedance values of 110 VAC and 220 VAC



The results of this project suggest the existence of a strong correlation between the impedances measured at 110 and 220 VAC. The almost perfect relation between the readings obtained at 110 and 220 VAC does not even compare with the imperfect correlation between the impedance at 6 VAC and 110 VAC (Figure 6-6). The less than close correlation between the impedance at 6 VAC and at 110 VAC might be explained by the difference in frequency (60 Hz vs 600 Hz). Some preliminary measurements (not presented here) suggest that there may be other factors which would explain this unequal association.

6.6 Duration of applied voltage

Most of the electrocutions were carried out with a power source of 110 VAC and a duration of 5 seconds (90/113, 80%), but a few electrocutions were done at 110 VAC and a duration of 15 seconds (13/113, 11.5%), a few others at 220 VAC and a duration of 5 seconds (6/113, 5%), some at 110 VAC and a duration of 10 seconds (2/113, 1.75%), and, finally, some others at 220 VAC and a duration of 3 seconds (2/113, 1.75%). The distribution of pigs that were electrocuted with a 5-second charge at 110 and 220 VAC according to weight category is presented in table 6-5.

Table 6-5. Number of pigs electrocuted with a 5 s charge according to weight category and voltage

Weight category (kg)	Voltage used for electrocution (V)		Total
	110	220	
< 5	9	2	11
5-24	32	1	33
24-50	21	3	24
50-80	17	0	17
>= 80	11	0	11
TOTAL	90	6	96

Electrocution at 110 VAC with a duration of 5, 10 or 15 seconds and a good connection (Lasso-rectal or Lasso-belt) was very effective as a means of killing all the pigs. Results using a duration of 3 seconds, a power source of 220 VAC and a good connection (Lasso-rectal) suggest a less convincing result.

Two pigs were electrocuted for a length of 3 seconds at 220 VAC to see if increasing the voltage would permit to decrease the length of time the current needs to be applied. The intensity of the current measured (~ 1.90 A) suggests that the observed flow of current at 220 VAC was probably twice as high as what would have been measured if electrocution was done at 110 VAC (Table 6-6).

Table 6-6. Measurement of intensity, impedance and voltage on two pigs given an electric charge for 3 s

Individual	Weight (kg)	Impedance (Ω)	Intensity (A)	Voltage (V)
1	24	118	1.96	231
2	35	123	1.87	230

The strength of the current measured at 220 VAC for 3 seconds was enough to kill the two pigs, but they did not die instantly after the current was stopped. Both of them responded to a pin-prick test (nociception reflex). The pupil still reacted for a few seconds and one of the pigs continued twitching. The pigs still died quickly (< 3 seconds after the current was cut). The experiment was not repeated because the operators considered that the information obtained from these two pigs was enough to suggest that a duration of 3 seconds was too short to electrocute them effectively.

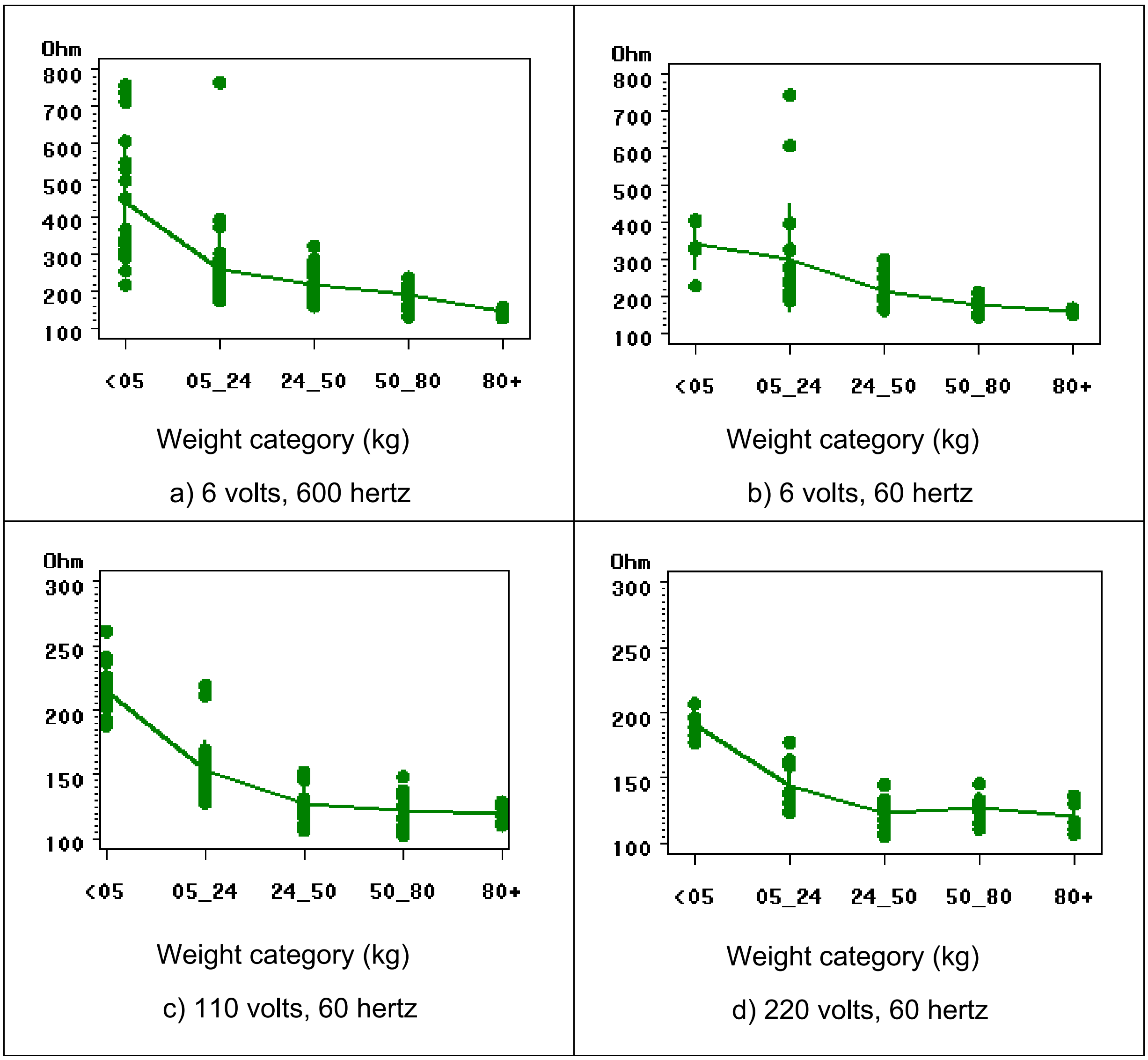
Observations concerning the behaviour of the pigs electrocuted in a 15 second time frame are slightly different than for those pigs electrocuted within 5 seconds. Several pigs electrocuted over 15 seconds collapsed before the end of the electrocution. Consequently, as described in the section Material and Method, the duration of the trembling phase was arbitrarily fixed at zero second.

Confirmation of the electrocution technique was carried out with a 110 VAC source and a duration of 5 seconds. When the commercial equipment was developed, the authors of this study recommended a 15-second duration.

6.7 Impact of animal's weight and body condition

The animal's weight had a significant effect on impedance ($P < 0.05$) evaluated at 6 volts 60 Hz, 6 volts 600 Hz, 110 volts 60 Hz and 220 volts 60 Hz. All data suggest that impedance decreases with the weight of the animal (Figure 6-8). Consequently, the flow of current should be stronger for heavier animals and weaker for piglets under 5 kg. The animal's body condition, evaluated subjectively (normal, under-nourished, cachectic) did not change the measurement for the impedance.

Figure 6-8. Relation among impedances measured under various voltages and frequencies for the Lasso-rectal connection



6.8 Current flow during electrocution at 110 VAC

Figure 6-9 shows that the current flow measured during electrocution of pigs with a 110 VAC power source and a good connection (Lasso-rectal or lasso-belt) increases with the weight of the pigs. The expected constant current (average) is 750 mA for light pigs and more than 1 ampere for heavier pigs

Figure 6-9. Current intensity (average ± standard deviation) obtained during euthanasia (110 VAC, 60 Hz) by weight category for the two selected connections (Lasso-rectal and Lasso-belt)

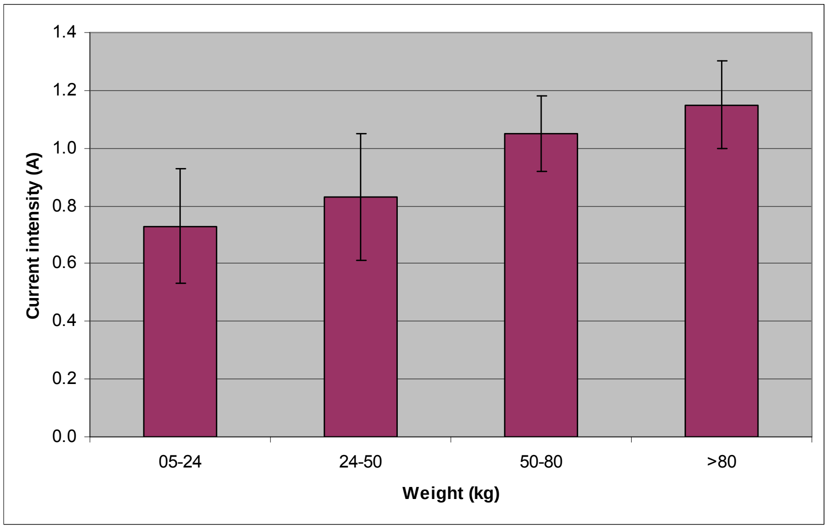
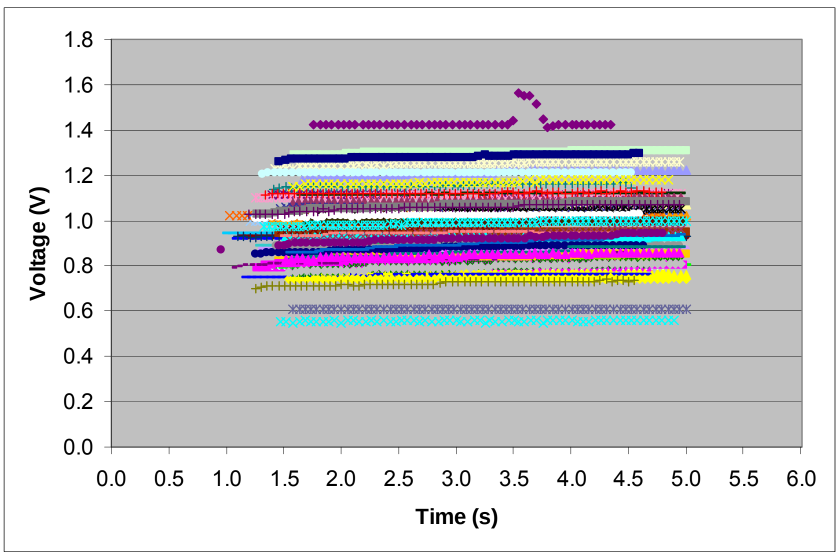


Figure 6-10 shows the stability of the current measured during electrocution of the pigs for both of the selected connections (Lasso-rectal and lasso-belt). The minimum value is 0.55 A and the maximum stable value is 1.42 A.

Figure 6-10. Current measured during electrocution of pigs (110 VAC, 60 Hz) for the two selected connections (Lasso-rectal and Lasso-belt)



The results of this work show that it is possible to electrocute pigs effectively with a current flow of 550 mA. Results of a previous study showed that current of 400 mA was sufficient to electrocute pigs effectively (Denicourt *et al.*, 2006).

The two selected combinations allowed high circulating currents (Table 6-7). Consequently, the final selection of a method was made based on criteria of effectiveness and ease of use. The belt could be adjusted to any and all sizes of pigs whereas an operator would need several sizes of rectal probes in order to ensure that the probe stayed in place. Using a rectal probe worked well for anaesthetized animals. However, only one non-anaesthetized pig was euthanized with this method because the pig made a continued effort to eject the probe. The risk of causing suffering to the animal would have been too high if the process would have been repeated without technical changes to the probe to make it stay put. As well, a technique requiring inserting an electrode in the pig's anus could easily repel some operators. For these reasons, the Lasso-belt technique was selected for development of commercial equipment.

Table 6-7. Comparison of characteristics of the two selected methods

Characteristics	Lasso-rectal	Lasso-belt
Installation of electrodes	Some restrictions	Very easy
Visual (aesthetic) effect of the technique	Unappealing	++
Increase of current during euthanasia (A/s)	0.00007	0.01
Current measured (A)	0.94 ± 0.15	1.00 ± 0.19
Adjustments for various sized animals	Requires several models in different sizes	Can fit all weight categories

6.9 Stunning by electrification (electronarcosis)

Electrical stunning tests were carried out on three pigs with 220 VAC voltage and on seven pigs with 110 VAC voltage. The stunning was carried out by applying a lasso (F1/8 or F3/16) around the upper jaw and a clip on the edge of each ear (2PPBO or 2PCBO) (configuration with three contact points).

The current measured between the electrodes placed on the animals' heads was very intense: 1.28 and 2.97 A respectively for 110 and 220 VAC (Table 6-8). The current flows were greater than the measurements reported by various writers with connections usually used at the slaughterhouse (Table 2-2).

Table 6-8. Measurements of strength of impedance in animals having received an electric discharge of 5 s on the head

	Stunning 110 V (n=7)		Stunning 220 V (n=3)	
	Impedance (Ω)	Intensity (A)	Impedance (Ω)	Intensity (A)
Average	95	1.28	76	2.97
Minimum	68	0.85	59	2.65
Maximum	141	1.70	86	3.33

Pigs stunned by electrification (electronarcosis) show the various epileptiform stages reported by other researchers (tonic phase, clonic phase and return to consciousness). The return to consciousness, judged by the return of the breathing reflex, was noted approximately 25 seconds after electrification. This length of time was similar to observations reported by other researchers (Table 2-1).

Observations of pigs behaviour during the clonic phase (stunning mode) were different from what was observed during the trembling phase (in euthanasia mode). The pigs stunned by electrification displayed considerable convulsion and paddling during the clonic phase. This type of behaviour had never been observed after electrocution. Paddling in a number of pigs was so intense that the operators were under the impression that the electronarcosis had not worked at all.

6.10 Piglets under 5 kg

Restraining piglets is both easier (they're lighter) and different than restraining heavier pigs. Piglets were electrocuted using the same techniques as the larger pigs (lasso-belt and lasso-anal probe) and several attempts were made by suspending the piglets by a hind leg (lasso-choker) or by a small chain around the abdomen.

The current measured with these various techniques is set out in table 6-9. The results were interesting, but the technique developed for this project is not adapted to piglets.

Table 6-9. Intensity (A) measured for piglets less than 5 kg according to connection and duration of electrocution at 110 volts

	5 s	15 s
Lasso-belt	0.551 ± 0.029	
Lasso-anal probe	0.552 ± 0.045	0.550 ± 0.083
Lasso-choker		0.288 ± 0.049
Average	0.552 ± 0.042	0.335 ± 0.115

7 Conclusions

The methodology of electrocution developed in this project is effective for killing all pigs from 5 to 125 kg with a power source of 110 VAC over a duration of 5 seconds. We recommend using the Lasso-belt technique and a duration of 15 s in order to guarantee death for more than 99% of pigs on the first attempt and render the animal completely inert as quickly as possible. Currently, this method of euthanasia by electrocution has been accepted by various Canadian organizations for compromised pigs from 5 to 125 kg.

Finally, it would be interesting to confirm this technique of euthanasia by electrocution for breeders (boars-sows). The success potential of the technique should be high because the data from the study suggest that impedance decreases the greater the weight of the animals, which should increase the current flow and promote a quick death. However, as we have mentioned in the report, it is absolutely necessary to confirm the technique on live animals since the path of an electric current can be altered by other factors related to the physical structure of adults (size, skin type, etc.) and, because of this, affect the effectiveness of the technique.

8 Developing a commercial device

8.1 Design

Before we went ahead with the design of a commercial device, the results of this study were presented to a sub-committee on animal welfare of the *Filière porcine du Québec* (Quebec pork stakeholders) (Appendix B).

The results of this study made possible to show that a device for electrocuting compromised pigs should have the following characteristics.

- Adequate restraint for the animal by a lasso on the snout and a belly belt;
- Restraining the animal must avoid handling which would create stressful situations and inappropriate pain;
- A 110-VAC alternating current between the lasso and the belt;
- Length of electrocution time should be 15 s. The tests carried out in this study demonstrated the effectiveness of a methodology of pigs electrocution while applying current for a period of 5 seconds. However, it is recommended that a commercial device be designed taking into account a duration of 15 seconds. Making this period longer makes it possible to guarantee effective death of more than 99% of pigs on the first attempt and will render the animal completely inert as quickly as possible;
- The electrical circuit should be completely independent of the public power source in order to avoid current leakage to the ground and to minimize any risk of electrocuting the operator;
- Design of the commercial device was given to Conception Ro-main.

Conception Ro-main developed a prototype of an electrocution carriage called SPEE (Figure 8-1). The first commercial version should be available in 2009. The SPEE is patent-protected (submission # 12/364097 registered 2 February 2009).

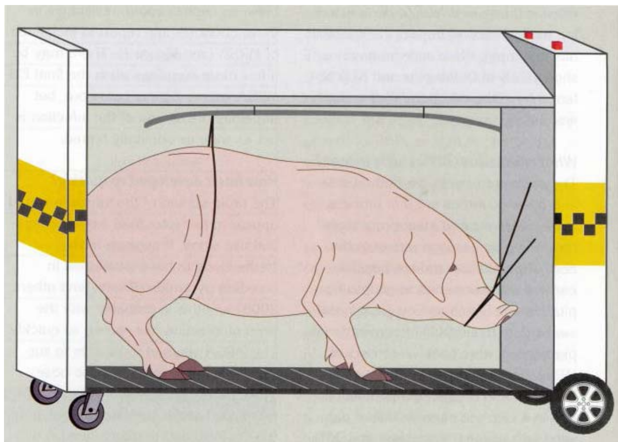
Figure 8-1. Prototype of SPEE electrocution carriage

The animal is restrained in a wheeled carriage, which makes it possible to get as close as possible to the animal to be euthanized and thus to avoid any handling which may create stressful situations and inappropriate pain (Figure 8-2).

The carriage is designed for easy washing and disinfecting.

The electrical system is integrated into the carriage and it functions with a 12 VDC battery (direct current). This battery holds enough power (in watts) to produce the required intensity for effective electrocution of pigs. Using a 12-volt battery in the electrocution carriage means that the unit is mobile without having to worry about access to an electrical outlet. As well, this specification guarantees that the device will be independent of the public power source. However, the battery must be recharged from a standard 110-VAC outlet between uses.

Figure 8-2. Animal held in a SPEE



Taken from Denicourt, 2008

An insert for the pamphlet « Euthanasie des porcs à la ferme – les options du producteur » by the *Fédération des producteurs de porcs du Québec* (FPPQ, 2003) has been prepared. This insert completes the information in the pamphlet and outlines the restrictions on use and the operating instructions for the commercial device (Appendix H). Information required to update the training brochure « Transport et euthanasie des porcs fragilisés » prepared by the *l'Institut de technologie agroalimentaire* (ITA) and by the FPPQ has been sent to these organisations. Thus, upcoming training will include the SPEE method of euthanasia. Two videos have been developed: a short video which presents and describes only the euthanasia and a longer one which presents the device and its characteristics in detail. The short video is available in three versions: without narration, with French-language narration and with English-language narration.

8.2 Process for euthanasia by electrocution

The work carried out as we were developing the product allowed us to document the various stages of an effective euthanasia by electrocution for pigs. The results gather from over 100 pigs of varying weights did not show any paddling or twitching movements in the limbs after 5 seconds.

Once the compromised pig has been led into the electrocution carriage, the various stages of an effective electrocution process are:

- The contact accessories, belt and lasso, must be in good condition before proceeding since good electrical transmission to the animal depends on them;
- The pig must be restrained using the metal belt, without over-tightening;
- The lasso must be secured around the upper jaw and adequately tightened before turning the crank to immobilize the animal;

- The metal belt around the pig's abdomen must be readjusted so that it raises the pig slightly above the floor;
- The doors must be closed before proceeding with the electrocution;
- The ignition key must be inserted into the lock and turned to « on »;
- Both of the illuminated buttons must be pressed to start the electrocution. A timer allows the operator to electrocute the animal for 15 seconds. The illuminated buttons make it possible to confirm that the device is functioning properly. When the illuminated buttons go out, open the carriage doors and check the state of the animal;
- The animal should be flaccid and hanging from the accessories;
- Pupils should be completely dilated;
- Touch the cornea (surface of the eye) to see that there is no movement or blinking. Any movement or blinking at this stage shows that there is still brain activity. In such situations, immediately repeat the euthanasia process or use another technique;
- Breathing and heartbeat must be absent after the electrocution phase;
- There should be no audible vocalization during or after the electrocution;
- Agonal gasps are frequent. They begin a few seconds after the end of the electrocution and may last from several seconds to several minutes. Don't worry; the animal is dead. Gasps generally last for one or two minutes after death, but may last longer. Our preliminary evaluation of the data suggests that using a sedative such as azaperone prior to the euthanasia by electrocution may counteract gasps. On the other hand, do not forget that it is harder to handle a sedated animal;
- Loosening of the sphincters (urinary and anal) may be observed after electrocution (depending on how full the bladder was).

What cannot not be seen inside the electrocution carriage:

- At power-on, the animal will undergo a major contraction of the whole body (« tonic » phase);
- Immediately after the current is shut off or even before, an animal which remained standing during most electrocution phase collapses.

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Appendix A Publication of results

Scientific publications

Denicourt, M., Klopfenstein, C., Dufour, V. and F. Pouliot. 2007. Développement d'une méthode d'euthanasie par électrocution pour les porcs en élevage et sécuritaire pour les travailleurs. Proceedings International Veterinary Academy of pain management annual meeting. Montréal, November 2, 2007.

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Denicourt, M., Klopfenstein, C. Dufour, V. and F. Pouliot. 2009. On-farm euthanasia: efficient and safe (110 VCA) pig electrocution. Proceedings of the American Association of Swine Veterinarians annual meeting, March, 7-10, 2009.

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Denicourt, M., Klopfenstein, C., Dufour, V. and F. Pouliot. 2007. Développement d'une méthode d'euthanasie par électrocution pour les porcs en élevage et sécuritaire pour les travailleurs. International Veterinary Academy of pain management annual meeting. Montréal, November 2, 2007.

Denicourt, M., Klopfenstein, C. Dufour, V. and F. Pouliot. 2007. L'euthanasie : la fin! Journée de formation aux producteurs de Pfizer. Duchesnay, November 23, 2007.

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Denicourt, M., Klopfenstein, C., Dufour, V., Lévesque, J., Turgeon, M.J., Pettigrew, D. and L. Ravary. 2009. Fiche technique FPPQ. Euthanasie des porcs à la ferme. Les options du producteur. Supplément électrocution. In press.

Université de Montréal, Centre de développement du porc du Québec inc. and Conception Ro-Main. 2008. Video. Euthanasie à la ferme par électrocution. Condensed version without narration; condensed version with narration; long version without narration.

Université de Montréal, Centre de développement du porc du Québec inc. and Conception Ro-Main. 2008. Video. On-farm swine euthanasia by electrocution.

Appendix B Québec swine industry – Animal welfare subcommittee

The October 26, 2007, the protocol and the project's results have been presented to some selected stakeholders participating to the animal welfare subcommittee of the Québec swine industry.

The participating stakeholders to this subcommittee were:

Martin Choinière	Association des vétérinaires en industrie animale
Nicolas Devillers	Agriculture and Agri-food Canada
Luigi Faucitano	Agriculture and Agri-food Canada
Camille Moore	Vétérinaire consultant
Marie-Claude Simard	Canadian Food Inspection Agency
Hélène Trépanier	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
Marie-Josée Turgeon	Fédération des producteurs de porcs du Québec

Appendix C Support letter

Université de Montréal

Comité d'éthique de l'utilisation des animaux

Le 23 octobre 2008

Madame Martine Denicourt
Professeure invitée
Faculté de médecine vétérinaire – Sciences cliniques

Madame Denicourt,

À votre invitation, les membres du Comité d'éthique de l'utilisation des animaux (CÉUA) ont visionné la méthode d'euthanasie que vous avez développée afin que le comité considère si cette méthode était acceptable pour l'euthanasie de porcs de la pouponnière à l'engraissement. Il nous fait plaisir de vous informer que la méthode que vous nous avez présentée a été jugée comme étant une méthode éthiquement acceptable pour l'euthanasie de tels porcs.

Je demeure à votre entière disposition pour toute information supplémentaire et vous prie de recevoir, Madame Denicourt, mes meilleures salutations.

La présidente du CÉUA,

Sophie Cuvelliez
Courriel : sophie.cuvelliez@umontreal.ca
Tél. : 8241

SC/lg

Appendix D Accuracy and precision of multimeters

Selecting the right instruments is paramount in order to obtain exact and precise measurements of both voltage and amount of current flow. The precision and the specifications of the multimeters used in this project (Fluke®, model 45) are laid out in table 9-1.

Specifications

For AC current, the Fluke® multimeter (model 45) calculates the true effective value of current and voltage (True RMS). This particular model of multimeter always calculates the stability of the measurements before displaying the results or transferring them to the RS-232 interface. The device lets you select various resolutions: 100,000 (slow), 30,000 (medium), 3,000 (fast) with reading rates of 2, 5 and 20 measurements per second respectively. The choice of resolution has an impact on the time required for stabilisation prior to receiving the first reliable reading after power-on. Finally, the instrument allows the user to measure two different parameters of the same signal from one test connection, and view both measurements at the same time (e.g., calculate voltage and frequency). Choosing the dual display mode slows down the reading speed (~ 1 reading every two seconds).

The precision of the Fluke 45 varies with the resolution (reading rate) and the range of the measurements. Measurements are more precise when the reading rate is “slow” as compared to “medium” and “fast” modes (Table 9-1). The precision of the instrument also depends on the scale of the measurement. The meter automatically selects the measurement range which makes for the most precise results. The available ranges for measuring voltage, density and AC current frequency are:

- 300 mV, 3 V, 30 V, 300 V and 750 V;
- 10 mA, 30 mA, 100 mA and 10 A;
- 1,000 Hz, 10 kHz, 100 kHz and 1,000 kHz.

Measurement precision for voltage and current decreases when the values measured are below 15% of the smallest range. In concrete terms, this means that the meter is less precise with voltages below 45 mV (15% of 300 mV) and with current below 1.5 mA (15% of 10 mA). The meter returns precise frequency measurements (± 0.1 Hz) as long as the voltage has an effective voltage of over 30 mV.

Table 9-1. Precision and specification of features for the Fluke® model 45 multimeter concerning measurement of current and voltage (1 measurement per instrument)

	Precision			
	Range	Slow	Medium	Fast
AC current	10 mA[1-2]	± 1 µA	± 10 µA	100 µA
AC current	10 A[1]	± 0.1 mA	±1 mA	10 mA
AC voltage	30 V	± 0.001 V	± 0.001 V	± 0.01 V
AC voltage	300 V	± 0.01 V	± 0.01 V	± 0.1 V
		Functional characteristics		
Stabilisation delay		1 s	1 s	300 ms
Rate of measurement		400 ms	200 ms	50 ms
Frequency		2.5 readings/s	5.0 readings/s	20 readings/s

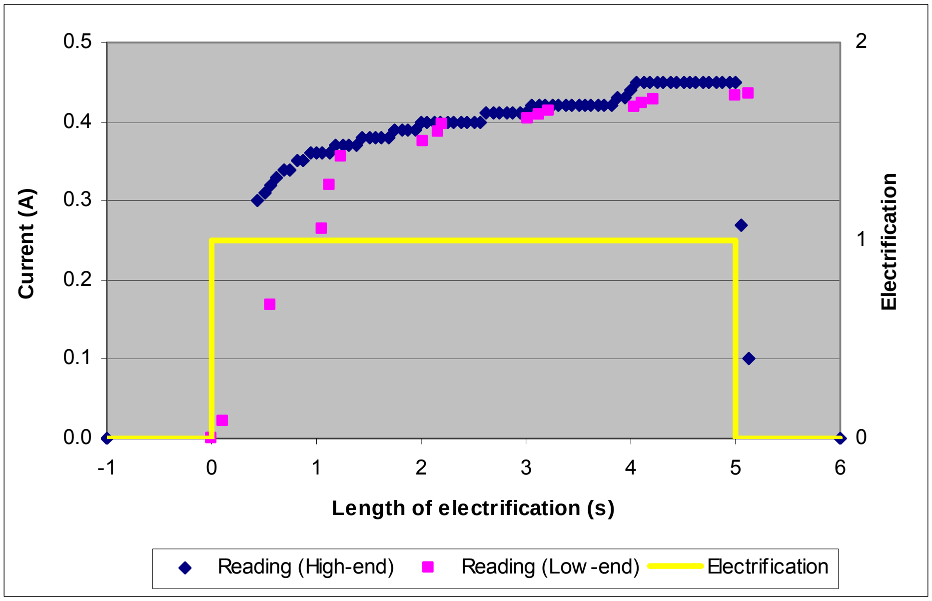
[1] Calculation of precision is valid between 15 and 100% of the range.
[2] Manufacturer's suggested precision is valid for measurements above 1.5 mA.

Limits associated with measuring instruments

In order to better understand the limits imposed by the specifications of the measurement devices, we compared two devices: the first is the high-end device used for this project, the Fluke®, model 45. The other is a less precise device (UEI, DM383B). The two devices were hooked up in series to the circuit required to electrify the pig (#68). Comparison of the readings from the two devices shows that:

- measurements gathered from the low-end meter suggest that the current flowing through the pig increases slightly after powering on. Measurements of the same current from the high-end device demonstrate that the measurements obtained from the low-end device are inexact during the first two seconds after power-on;
- the first stable measurement displayed by the high-end device appeared around 500 milliseconds after power-on. This wait period corresponds to the manufacturer's specifications (Table 9-1);
- both instruments show measurement of current not equal to zero when the power to the circuit is cut. The response time of the high-end meter is faster than that of the low-end instrument. For both meters, it is difficult to confirm the exactitude of the displayed current after source power has been cut off.

Figure 9-1. Comparison between measurements displayed by high-end (Fluke®, model 45) and low-end (UEI, DM383B) instruments during electrification of a pig (# 68). The left axis shows the level of current displayed by the two devices and the right axis shows the power-up during electrification.



Limits imposed by the meters for characterizing the electrification of pigs

Limitations regarding measurement of current (< 1.5 mA)

During the development of techniques for electrocuting pigs, the authors of this project used the following power sources:

- 4 - 6 VAC, 60-60,000 Hz;
- 110 VAC, 60 Hz;
- 200 VAC, 60 Hz.

Considering that the expected impedance between the two electrodes should be situated between 250 and 2,500 Ω, the expected current flow comes near the sensitivity limit of the two meters (1.5 mA) at lowest voltages (4 volts/2,500 Ω = 1.6 mA). Calculations of current below 1.5 mA must be considered as imprecise and interpreted with great caution.

Limitation concerning first available measurements

The specifications of the two instruments and comparisons between them (Figure 9-1) suggest that it is difficult to obtain reliable measurements during the first second following power-on. The high-end meter produces a reliable measurement more quickly than the low-end meter. However, for both instruments, it must be kept in mind that initial measurements displayed are probably downwardly biased with respect to reality.

Limits concerning last available measurements

The tests demonstrated that both meters showed levels of current not equal to zero after the current was cut off. These levels of current may have been real or may have been simply artefacts explicable by the limits of the instruments. For purposes of this project, the authors considered that the last measurements of voltage and current located between the nominal value (last stable measurements) and zero value are probably artefacts. These measurements were thus eliminated when confirming the database (see appendix on data processing and multimeters).

Appendix E Processing electrification data

Data structure during collection

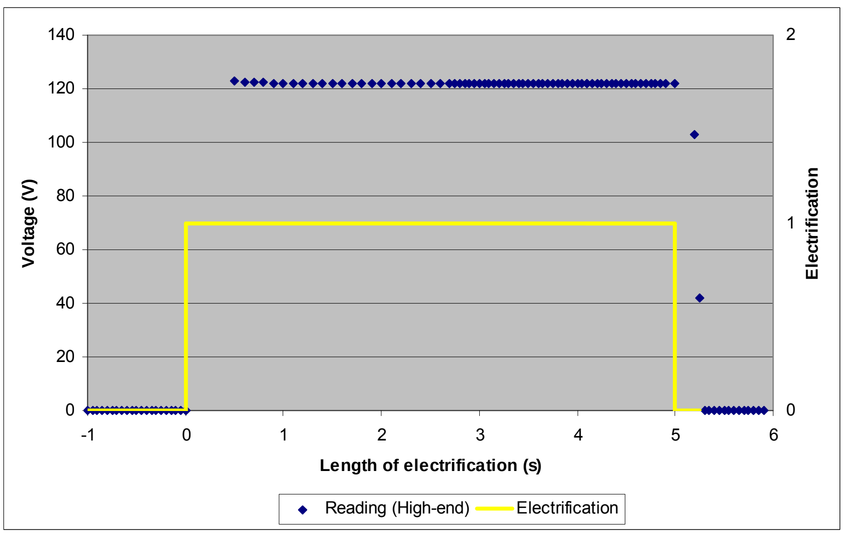
After collection, the Access database contained various types of data:

- Measurements recorded at the right time (> 90% of data);
- Measurements recorded before and after electrification of pigs under domestic voltage;
- Measurements recorded when no piglet was hooked up;
- Measurements when the instruments were not properly adjusted.

Each series of measurements corresponding to an electrification was identified with a unique identifier. An electrification was characterized by a connection type, a voltage and a given frequency and by the pig's status (dead or alive).

Data sample

Figure 9-2. Characteristics of measurements taken by the Fluke®, model 45 multimeter during electrification of a pig (#68). The left axis shows the current as displayed by the meter and the right axis shows the voltage during the electrification.



Figures 9-1 and 9-2 show the information recorded in the Access database prior to confirmation. Processing the data allowed to eliminate superfluous measurements (before and after electrification) and to standardize the temporal measurements (x axis).

Data processing

With the exception of measurements taken for two particular pigs (ID 325 and 472), that required special processing, all voltage data under 3 volts were eliminated. Where measurements gathered in “Euthanasia” and “Stunning” modes are concerned, voltage data under 100 volts was also eliminated. For these same two modes, missing frequencies where voltage data was available were fixed at 60 Hz.

On occasion, data associated with a particular case were only confirmed some time after the measurements were taken (2-3 seconds). In these cases, the beginning of the period where data was valid was indicated in the database and measurements taken outside of the period were eliminated.

Times recorded in the database were rounded to the closest second. Since data for voltage and intensity were recorded several times per second for “Euthanasia” and “Stunning” modes (and sometimes for “Impedance” mode), it was necessary to estimate the time of measurement. Estimated times were obtained either by interpolation (time situated exclusively between the first and the last second) or by extrapolation (first or last second) using linearization by means of the “Proc Expand” procedure from “SAS” using the “join” feature.

Since times were initially reported in a time-of-day format, measurement times with a time scale setting zero at the start of the measurement period had to be calculated. In order to do this, times were calculated beginning with the most recent voltage measurement. Time at the most recent measurement was therefore made equal to the length of the electrocution that was recorded in the database. This duration of electrocution is relatively precise since it represents the duration that was programmed into the control feature of the electrocution device. Times of previous measurements were then calculated using this most recent time. Using the most recent measurement time as a reference instead of the first measurement time is justified by the fact that the instrument does not display any measurement in the first moments of the electrocution since the meter needs several milliseconds to become stable.

As well, voltage and intensity data for a particular pig having more or less four standard deviations were considered as being missing. Moreover, for intensity data in “Euthanasia” and “Stunning” modes, a regression line was established for each pig, relating the intensity to the measurement time, which had been previously scaled to have a zero average. The intercept of the regression thus returned the predicted intensity at the mid-point of the measurement period. Afterwards, intensity data below one third of the intercept were eliminated.

Voltage and intensity data were combined in the same database based on the particular pig and the measurement time. Since the measurement times for voltage and intensity did not often correspond, the intensity data were interpolated or extrapolated depending on various measurement times for voltage and intensity by linearization by means of the “Proc expand” procedure from “SAS”, using the “join” feature. This was done in order to make it possible to calculate the impedance (ratio volt/ampere), as a function of voltage measurement time. Impedance was calculated when intensities were greater than 0.02 A.

Lastly, some measurements were eliminated manually since they had not been rejected by the various automated procedures for data validation (e.g., data recorded after the electric current was shut off).

Appendix F Anaesthetic protocol and effect of azaperone

Anaesthetic protocol

In order to proceed with the various phases of the experiments (phases 1 and 2), pigs had been previously anaesthetized. The anaesthetic protocol was made up of a combination of drugs making it possible to use an analgesia and a moderate anaesthesia in order to minimize pain and not mask brain activity.

To start with, pigs were sedated with azaperone (Stresnil™ injection, Merial, 2.2 mg/kg). Fifteen minutes after treatment with azaperone, they were given atropine sulfate (Atropine sulfate injection, Bimeda-MTC, 0.04 mg/kg) and ketamine chlorhydrate (Ketaset®, Wyeth Animal Health, 11 mg/kg). All of the drugs were given by intra-muscular injection. Once anaesthetized, the pigs were laid out on rubber mats for the length of the experiments.

Azaperone is a sedative. The animal remains conscious but calm and indifferent to its environment. The pigs were given azaperone around 15 minutes before the atropine and ketamine.

Atropine is an anticholinergic, antispasmodic and mydriatic drug which was used to avoid an excess of bronchial, gastric and salivary secretions and to control intestinal hypermotility. It was injected into the pigs to control the side effects of ketamine.

Ketamine is an anaesthetic characterized by a profound analgesia, retention of pharynx and larynx reflexes and muscle tone of skeletal muscles, a slight cardiac stimulation and slight respiratory depression. There is sometimes presence of slight salivation. Other reflexes, (e.g., corneal, paddling, etc.) are also maintained. In addition, the eyes remain open normally and the pupil remains dilated. Premedication with atropine may, to a certain extent, reinforce and prolong anaesthesia.

Sedation protocol

Some pigs (phase 3) were given a simple sedation before proceeding with the euthanasia. These pigs were sedated with azaperone (Stresnil™ injection, Merial, 2.2 mg/kg).

Effects of azaperone (Stresnil™ injection)

Stresnil™ (azaperone), a butyrophenone, affects the dopaminergic and adrenalgic pathways by blocking, by competition, the dopamine receptors and adrenaline alpha-1 receptors.

By blocking the dopamine receptors, Stresnil™ causes a depression of the central nervous system (CNS). Butyrophenones are used, among other things, to control Parkinson's disease in human medicine.

By blocking the adrenaline alpha-1 receptors, Stresnil™ affects the sympathetic pathway of the afferent pathway of the autonomic nervous system (ANS). Thus mydriasis, tachycardia, arterial hypertension, vasoconstriction and lowering of the threshold of normally observed reactions in cases of shock are inhibited or lessened when Stresnil™ is administered. Alpha-1 blockers can also decrease the capacity of the trigone[10] to constrict and so facilitate emptying the bladder.

The gasping reflex that is observed during hypoxia is inhibited or shortened when serotonin A-1 blockers are administered. Buflomedil is known to be a blocker of serotonin thanks to its butyrophenone structure. Since Stresnil™ is also a butyrophenone, we can presume that it has the same effect on the gasping reflex.

10 Vesical trigone or Lieutaud's trigone = A smooth triangular area on the inner surface of the bladder, limited by the apertures of the ureters and urethra