Electrical stimulation efficiency and distribution of electric potential and electric field along lamb carcasses

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Introduction

Due to the depletion of ATP-stored muscle energy, electrical stimulation of meat carcasses on the slaughter line accelerates the onset of rigor mortis and the rate of post mortem glycolysis : thus, the pH can drop to values inferior to 6,0 within 2 hours following death. In these conditions, the risks of meat toughening due to a rapid chilling (cold-shortening) or early freezing (thaw-rigor) can be avoided. The demands of hygienists (reaching a deep temperature of 7 °C 24 h post mortem) can be satisfied while the meat is kept tender.

Accelerated processing by hot boning of muscles is a promising technology for the future of the meat industry. Coupling the practice of boning unchilled carcasses with that of electrical stimulation is a means of reaping the benefits of hot boning without any risk of cold-shortening (TAYLOR and al., 1980). Thanks to electrical stimulation, carcasses can now be boned 4 to 5 hours post mortem with all safety for tenderness.

Many electrical parameters of E.S. have already been studied (BENDALL, 1980; CHRYSTALL and al., 1976). The efficiency of this technology is mostly measured by the drop in pH of the muscles during stimulation, or by the time taken by the muscle to reach pH 6,0 (CARSE, 1973). However, a large variability of effects can be observed for various muscles throughout the carcass, and for various types of animals. These discrepancies can be partly explained by the metabolic type of muscles (HOULIER and al., 1981), but they can also be due to an uneven distribution of the electric field among the muscles (BENDALL, 1980). Although the resistivity, impedance and capacitance of meat have been previously measured (SALÉ, 1976 ; SWATLAND, 1980), there is a lack of data concerning the conduction of the electric stimulation current through a meat carcass.

The differences in the biological tissues composing the carcass as well as its geometry are factors modifying the impedance and can be partly at the origin of the variations of the electric field (SALÉ, 1980).

This study was designed to evaluate the variability of the electric field along lamb carcasses, in connection with electrical stimulation. It is divided in 3 parts :

- the distribution of the electric potential, and consequently the electric field along lamb carcasses in non-stimulating conditions. The study of the electric field during high voltage stimulation would have shown a danger for the operators and for the equipment due to the high voltage. To get free from these problems, lower sinusoidal voltage currents were mainly used, so that one should observe the same distribution of the electric potentials on a reduced scale ;

- then, as a checking, we made experimentations with a genuine high voltage electrical stimulator and direct measurements of the electric field on muscles ; ...

- finally, in order to investigate the effects of the carcass geometry and of the position of the stimulation electrodes, a scale moulded model of a carcass needed to be built. This paper presents preliminary results of measures made in view of establishing, in the future, a cartography of the electric field.

Materials and methods

For the studies 1 and 2, the experimentations were carried out on eight male Limousin lambs of fifteen to seventeen kg of carcass weight. Lamb meat was used in these studies because it shows the same general biochemical and physical responses as other meats (CARSE, 1973 ; BOWLING and al., 1978) and it is lower in cost per carcass and easier to handle than beef carcasses.

The electric measures were taken approximately 20 minutes post mortem, after dressing. The experimental conditions were fixed as follows :

1 - In the first experimentations, the electric contact was made by two sets of electrodes which were inserted on the inside of the rear legs, near the Achilles tendon and anterially to the humerus. The current had a frequency of 1 000 Hz ; the electric potential was measured using a probe connected to a cathode ray oscilloscope for voltage output.

2 - In the second experimentations, the electrodes were placed at the severed neck muscles and the Achilles tendon. They were connected to a stimulator giving pulses of square wave, at 600 V peak voltage of frequency 12,5 Hz during 2 minutes. In these conditions, electrostimulation occured and during the stimulation, the electric field was directly measured using a two-needle probe, which gives the difference of potential on a fixed length (2 cm). Measures were made on several choosen muscles : M. Supraspinatus, M. Triceps brachii (caput longum), M. Rectus femoris, M. Flexor digitorum superficialis and M. Longissimus dorsi. The values of the electric field were read from the screen of a cathode ray oscilloscope.

Another study consisted in the investigation of the influence of the geometry on the distribution of the electric field on a carcass : the influence of the position of the stimulation electrodes. However, these measurements could not be done on genuine lamb carcasses because the resistivity of biological tissues depends a lot of the temperature : it would have introduced other causes of variability. To break free from these difficulties, a copy of half-a-carcass of lamb was built by moulding with a silicone shell, placed in a wooden box. This moulded pattern, stable in the course of time had the same geometry as half-a-carcass of lamb. This mould was filled with a solution of Potassium chloride 0,15 M. The upper side of the wooden cover of the mould was squared with holes allowing to introduce electrodes in definite places. The applied current from the generator was an alternating current (8,5 volts ; 1 000 Hz). The measuring probe was made of a metal stem and isolated except at the end, allowing to measure the electric potentials at different places.

Results and discussion

Study 1 - Distribution of the electric field along a lamb carcass

Figure 1 indicated the distribution of the electric potential and the electric field in non-stimulating conditions when a sinusoïdal (10 V ; 1 000 Hz) electric current passes through the carcass.

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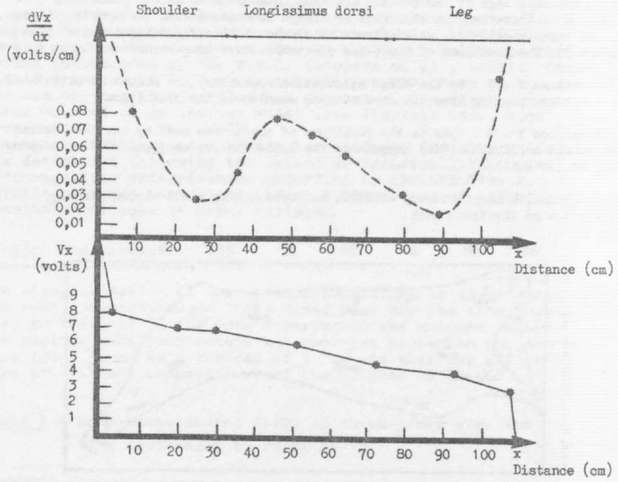

Figure 1 - Distribution of the electric potential Vx and of the electric field on lamb carcasses (HOULIER, 1981)

The average electric field dV/dx, expressed in Volts/cm is also reported in figure 1. This figure allows us to draw two main conclusions :

a) The electric field varies a lot along the lamb carcass : the results show that the electric field is much higher in the parts where the section is smaller (Longissimus dorsi) than in big muscle volumes (leg and shoulder). The effect is directly under the dependance of carcass geometry.

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b) There is a very sudden drop in potential in the vicinity of the electrodes. This shows the double effect of the polarization at the level of the electrodes and the geometry of the bundle of muscles (particularly in a small section). Therefore, only 40 per cent of the total voltage applied is, in these conditions, used to create an efficient electric field in the major part of the carcass. So, if one applies a voltage of 600 volts between both ends of a lamb carcass 1 m long, the effective electric field would not be 6 volts/cm but only 40 per cent of this value.

Therefore, very high voltages and currents would be necessary largely to overcome the electrode impedance (contact resistance) and to ensure the correct wanted electric field.

Study 2 - Electric field measured on 5 stimulated muscles

In another experiment, we measured directly the electric field of 5 different lamb muscles during stimulation. The results of table 1 confirm that the electric field is very variable throughout the carcass during stimulation. High values of electric field were measured in M. Longissimus dorsi and very low values -3 to 4 times lower- in the shoulder muscles e.g. M. Supraspinatus and Triceps brachii.

However this heterogeneity of the electric field cannot explain alone the variations of the efficiency of the electrical stimulation : m. Supraspinatus and m. Rectus femoris placed in the same electric field show a different drop in pH.

Muscle	Electric field (Volts/cm)	Position of muscle	Δ pH
- Supraspinatus..................	1,4	shoulder	0,57
- Triceps brachii (caput longum).	1,5	shoulder	0,72
- Rectus femoris.................	1,5	leg	0,65
- Flexor digitorum superficialis.	5,5	leg	0,69
- Longissimus dorsi..............	4,0	back	0,70

Table 1 - Values of the electric field directly measured and drop in pH of 5 muscles choosen for their position, during stimulation of a lamb carcass (600 V ; sq. wave ; 12,5 Hz)

Such a high voltage stimulation current (600 V peak) for a lamb carcass does not allow us to see the complete variability of the drops in pH, which would probably be the case if the overall voltage was lower.

A lot has still to be done to get a uniform electric field along the lamb carcass during electrical stimulation. Varying the positions of the stimulating electrodes would allow major modifications of the distribution of the electric field.

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Study 3 - Influence of the positions of the electrodes on the distribution of the electric field

For every electrical stimulation equipment manufactured until now the rail at which the back legs of the carcass are hung is considered as one conducting electrode : therefore, an electrode is always in contact with the Achilles tendon. In our experiments also, an electrode is always at this place (position n° 5 on figure 2). The positions of the other electrodes have been varied on places 1 to 4.

a) Positions 1 - 5 : by the MEDAL stimulation apparatus, the animal is stimulated by a current passing from the severed neck muscles to the back legs.

b) Positions 3 - 5 : this is the positions of electrodes used by the New-Zealand (CHRYSTALL & HAGYARD, 1976) stimulator for lambs and the american KOCH stimulator adopted for cattle.

c) In France, a manufacturer, SUCMANU, has been making a stimulator placing electrodes at the front legs.

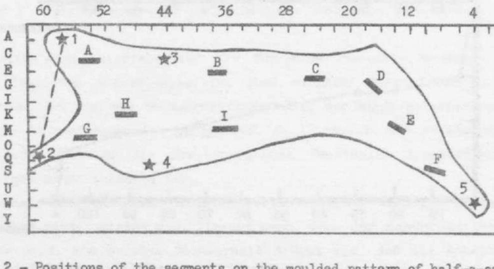

Figure 2 - Positions of the segments on the moulded pattern of half-a-carcass of lamb where the electric field was measured (A to I) and positions where the contact electrodes were inserted (1 to 5)

d) In our study 1, the main part of our work was done by placing the electrodes at the front legs and at the rear legs. Such variations in the positions of the electrodes imply inevitably important discrepancies in the distribution of the electric field, which we studied on the moulded pattern. Five positions have been selected for the electrodes.

A first series of electric measures has been done after filling the moulded pattern with a solution of Potassium chloride assuming that the electrical resistivity of all the tissues is the same. As the measures were done with an alternating current of frequency 1 000 Hz, the phenomenons of polarization due to the interface electrode/carcass were negligeable.

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From the measured figures, the electric field was recalculated by referring the measured values to a voltage of 600 volts. Therefore, we used the following formula :

$$E = e \times \frac{V}{v \times d}$$

where : E = electric field (volts/cm)
e = voltage measured between 2 electrodes allowing the measurement of the electric field
d = distance between 2 measuring electrodes : 4,5 cm
v = voltage between the 2 main electrodes : 8,5 volts
V = 600 volts (stimulated high voltage stimulation)

The results of the measures are indicated on table 2. The comparison with results obtained previously on a genuine lamb carcass allows a good appreciation of our modelization.

Position of electrodes	PARTS OF THE CARCASS FOR MEASURES OF ELECTRIC FIELD								
	A	B	C	D	E	F	G	H	I
	Sterno-mandibularis	Longissimus dorsi	Longissimus dorsi	Saddle	Leg	Flexor digitorum superficialis	Shoulder	Triceps brachii	Diaphragma
ON A MOULDED MODEL OF CARCASS									
- 1 - 5	1,96	3,01	4,00	2,20	2,50	3,45	0,62	1,49	2,22
- 2 - 5	0,55	2,43	3,40	1,91	2,20	3,32	2,38	2,18	2,04
- |1 + 2| - 5 .	1,57	2,90	3,60	2,35	2,67	3,48	1,41	1,49	2,51
- 3 - 5	0	3,18	3,54	2,35	2,67	3,37	0,16	0,70	2,11
- 4 - 5	0,31	2,58	3,92	2,16	2,51	3,37	0,16	0	2,67
ON A LAMB CARCASS									
- 2 - 5	/	4,00	4,00	/	/	5,5	/	1,5	/

Table 2 - Electric fields (in volts/cm) in different parts of the moulded model of ½ carcass of lamb for 5 positions of electrodes

On all the areas, the calculated electric field on the pattern was smaller than the electric field measured on a lamb carcass post mortem : this may result from a lack of precision on the localization of muscle areas on the pattern ; and also mostly because of a larger conduction section because of the lack of bones.

Other measures were done after placing the bones into the moulded pattern (table 3). For position 2 - 5 of the electrodes, the introduction of the skeleton brings an increase of the electric field namely for the areas of Longissimus dorsi and shoulder ; consequently, the electric field dropped at the leg area.

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Position of electrodes	PARTS OF THE CARCASS FOR MEASURES OF ELECTRIC FIELD								
	A	B	C	D	E	F	G	H	I
	Sterno-mand.	Long. dorsi	Long. dorsi	Saddle	Leg	F. dig. superf.	Shoulder	Tr. brachii	Diaphragma
ON A MOULDED MODEL OF CARCASS									
- 1 - 5	1,96	2,51	3,76	0,78	1,17	15,6	0	1,57	3,06
- 2 - 5	0,78	4,70	4,39	0,78	1,10	36,9	4,70	2,98	2,20
- |1 + 2| - 5.	1,25	4,62	3,92	1,33	1,88	34,5	1,33	1,80	2,20
- 3 - 5	0	1,96	2,04	0,78	1,41	32,9	0,70	0,47	1,02
- 4 - 5	0,31	4,08	0,31	1,10	1,41	29,0	1,41	0	0
ON A LAMB CARCASS									
- 2 - 5	/	4,00	4,00	/	/	5,5	/	1,50	/

Table 3 - Electric field (in volts/cm), referred to 600 V peak voltage, in various parts of a moulded pattern (containing the varnished skeleton and a solution of KCl) for 5 positions of the electrodes

One of the important problems of electrical stimulation remains undoubtedly connected with the electrodes.

For certain positions of the electrodes, areas such as A, H and I can be placed in a nearly inexistant electric field : these are the areas of the neck and the shoulder in cases when electrodes are placed in 3 - 5 and mostly in 4 - 5. In practice, these places are those of the New-Zealand and american (KOCH-type) equipment (SMITH, 1977) : this shows how difficult it is to stimulate properly the forequarters with these processes.

A similitude with a beef carcass could be done and these results could be approximately applied to a beef carcass. Using the electrodes placed between the severed neck muscles and the Achilles tendon, like in the MEDAL process, the neck area can be efficiently stimulated and, of course, the back and the leg also. An important result of this study is that the most difficult areas to stimulate homogeneously are those of the shoulder. An ideal position for the electrodes |1 + 2| - 5 would be one electrode at the severed neck muscles, one at the front legs and one at the Achilles tendon : then, we could reach towards an ideal distribution of the electric field.

Conclusion

The discrepancies remaining between the various areas cannot practically be eliminated. The only means remaining for the technologist is to increase the general level of the electric field, therefore the peak voltage, above a certain threshold. Thus, the voltage should be increased so that the worst situated areas are submitted to a sufficient electric field for stimulation.

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The differences in the geometry and the electrical resistivity of the different parts of the carcass on one hand, and phenomenons of electric contact electrode/muscle tissue on the other hand, combine with each other to modify the intensity of the electric field. A cartography of the electric field in the stimulated carcasses remains to be done for the type of animal and the position of electrodes can have an influence on the design of the equipement for high voltage electrical stimulation ; this would help manufacturers as well as users of this type of slaughter equipment.

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