In: Meat and Meat Processing. ISBN: 978-1-53612-210-7
Editor: Derrick B. McCarthy @ 2017 Nova Science Publishers, Inc.

Chapter 5

THE USE OF ELECTRICAL STIMULATION IN MEAT PRODUCTION

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ABSTRACT

The present chapter describes what is known about the effects of the use of electrical stimulation of carcasses of meat animals, including the effects on meat tenderness and meat sensorial characteristics. Electrical stimulation as a process involves passing an electric current through the carcass of freshly slaughtered animals. Electrical stimulation has been extensively used since the 1950s to hasten the onset of rigor mortis and to modify steps of the glycolytic pathway. Many studies conducted in the USA, in New Zealand, Australia and Europe have involved a variety of electrical stimulation methods on different types of meat animals. Data reported in many studies suggest that electrical stimulation, through hastening rigor changes, can significantly reduce in the carcasses of meat animals the phenomenon of cold shortening, one of the major cause of meat toughness. Although it is well established that electrical stimulation increases the rate of *post mortem* glycolysis, other biochemical and biophysical effects have been implicated with the use of this technology, including the possibility that electrical stimulation also results in physical disruption of muscle structure. Electrical stimulation can be considered as a part of the total meat production chain from slaughter to final sale, and has particular advantages for hot boning, where the shortening and toughening conditions that would occur for non stimulated muscles during chilling are avoided.

Keywords: electrical stimulation, meat production, meat tenderness.

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INTRODUCTION

Tenderness is generally judged as the most important quality parameter of fresh meat. A number of procedures have been developed for increased meat tenderness: suspension via the pelvic bone, mechanical restraint of muscles, conditioning, cooler ageing, high temperature conditioning, delayed chilling, blade or needle tenderization, use of tropical plant or fungal enzymes, etc. (Polidori et al., 1996). All of these procedures cause changes in meat tenderness via effects on the contracting machinery (muscle fibres), the collecting-harnessing-reinforcing structures (connective tissues), or both. Factors affecting muscle tenderness have been extensively studied over the past 50 years. Initially, the connective tissue component of meat received the greatest attention; since 1960, the state of muscle contraction following *rigor mortis* has been the most intensively studied (Ouali, 1990; Thompson, 2002).

The discovery that muscle shortening is one of the major causes of meat toughness has led to the realization that *post mortem* treatments will usually outweigh live-animal factors such as breed, age, stress and preslaughter state in determining palatability (Locker & Hagyard, 1963; Marsh & Leet, 1966; Penney & Dransfield, 1979; Jeacocke, 1984). Since cold shortening and, indeed , thaw shortening occur only in *pre rigor* muscle (Marsh & Thompson, 1958), it is evident that these can be prevented by ensuring that *rigor mortis* is achieved before meat is either chilled or frozen. Rigor development in meat producing animals can take up to 36 h, so the aim of the meat scientists has been to hasten *rigor mortis* process, defined when adenosine triphosphate (ATP) production ceases. Early muscle studies indicated that rigor development can be brought forward by ante mortem stress, by maintaining a high carcass temperature or by electrical stimulation of carcasses (Chrystall & Devine, 1985). The first approach is in conflict with the actual legislation concerning animal welfare; the second one is expensive, and for this reason is not widely applied. Electrical Stimulation (ES) of carcasses soon after slaughter emerges as the most ingenious and practical approach in inducing early *rigor* development. It does this by causing muscles to undergo work via anaerobic glycolysis, resulting in an initial pH fall (ΔpH) followed by a change in the rate of pH fall (dpH/dt); the combined effect is that the muscles enter *rigor mortis* before the muscle temperature falls to values producing cold shortening and toughening (Devine et al., 2014).

Rigor Mortis

The merit of using ES in meat technology is intimately associated with the development of *rigor mortis* in muscle, with the cold shortening phenomena, with thaw *rigor*, and with meat ageing. Brief attention is therefore given to these topics in preparation for the more extensive discussion on ES which follows.

After an animal dies, its muscles live on in the *pre rigor* state. They are reversibly extensible and can be excited to contract. If starved of oxygen, they enter *rigor mortis* some minutes or hours *post mortem* and become nonexcitable and rigid. It is obvious that, in the carcasses of meat animals, various muscles will have different rates of fall of temperature *post mortem*, according to their proximity to the exterior and their insulation. As a result, the rates of *post mortem* glycolysis will tend to be higher in muscles which are solw to cool, and vice versa (Lawrie, 1991). From extensive studies of *rigor* development, it is evident that the biochemical changes are likely to be the same for all vertebrate species, with the disappearance of ATP and creatine phosphate (CP) and, in glycolytic activity, the appearance of considerable quantities of lactate ions, up to 100 μmol/g muscle (Chrystall & Hagyard, 1976; Lee et al., 2000; Hopkins et al., 2014). The ultimate pH of muscle is inversely related to the accumulation of these ions, being relatively high (approximately pH 7.0) in excessively exhausted animals and low (approximately pH 5.5) in well fed and rested animals (Hopkins et al., 2011).

Cold Shortening

The tenderness of meat removed from the carcass in a *pre rigor* condition is highly dependent ion the extent of the cold shortening which occurs after excision (Marsh & Leet, 1966). The relationship between shortening and tenderness is complex; Locker & Hagyard (1963) examined the shortening which accompanies or precedes *rigor* onset at low temperature (2°C). Their investigations revealed an interesting cold shortening phenomenon in which the exposure of excised fresh bovine muscles to temperature near the freezing point causes very appreciable shortening. Muscle from beef animals shortens by 50% or more prior to and during the development of *rigor mortis* if held at 2°C (Chrystall & Devine, 1985). The magnitude of this so-called cold shortening increases with the drop in temperature toward 0°C and it is reduced by increasing *post mortem* delay before chilling.

Red muscles are relatively susceptible to cold shortening, while so-called white muscles are minimally affected by the conditions which cause cold shortening (Devine et al., 1984). A few muscles such as the muscles of the neck, are severed during carcass dressing and are likely to shorten. Some other muscles, such as the *Longissimus dorsi*, remain attached to the skeleton, but since most of the constituent fibres insert into flexible epimysium, the muscles are able to shorten. In fact, even muscles that are fixed at both ends are capable of cold shortening over a part of their length if they are subjected to a differential chilling rate along their length. Shortening produced in *pre rigor* muscle is the greatest possible cause of toughening in cooked meat, animal age can be merely a secondary cause (Devine et al., 1999). If *rigor* muscle is aged for a number of days before cooking, it usually becomes appreciably more tender. The decrease in tenderness which is associated with the onset of *rigor mortis* is gradually reversed as the time of *post rigor* conditioning increases (Lawrie, 1991).

Electrical Stimulation

The association between meat and electricity dates back to some of the earliest muscle physiology experiments: from Galvani's time the use of electricity to study muscle function increased (Chrystall & Devine, 1992). The earliest reported use of electricity for meat improvement is its purposed by Benjamin Franklin in 1749 to electrocute turkeys with the result that they were uncommonly tender (Devine et al., 2014). During the 1950s it was shown that ES could improve meat tenderness of beef, but no commercial application of the process occurred. Stimulation of horse muscle has been used to facilitate a trial of microbial growth on pre *rigor* and *rigor* muscles from the same animals (Ingram & Ingram, 1955).

Several hypotheses have been suggested that would account for the meat tenderizing action of early *post mortem* ES. The originators of the process (Harsham & Deatherage, 1951) proposed that activity of acid proteases was increased by the rapid acidification induced by the treatment. The subsequent discovery of cold shortening led, some years later, to an alternative explanation, according to which ES accelerates *rigor* onset and so prevents shortening and the toughening associated with it (Hwang et al., 2003).

The incorporation of ES into the slaughtering process was first used in New Zealand (Carse, 1973) and then Australia to avoid toughness resulting from cold shortening. ES has become of increasing interest to meat processors because it requires little changes in normal abattoir practice and the removal of

meat from the carcass *pre rigor* (hot-boning) could become a practical possibility. ES involves passing an electric current through the bodies or carcasses of freshly harvested animals. This electric current causes the muscles to contract, increasing the rate of glycolysis and results in an immediate reduction in muscle pH (ΔpH) that ranges from 0.6 pH units at 35°C to 0.018 units at 15°C, suggesting that ES of warm carcasses should take place soon after slaughter to maximize efficacy (Devine et al., 2014).

There are several physical methods by which ES could be applied, many different possible electrical specifications, ad in reality many different perceptions of the response. Most commercially used ES systems employ the conveying rail as ground, and a live electrode contact some other part of the body, carcass or side. In the most basic systems the live electric contact is a clip manually applied to the head end of the animal's body that is suspended by one or both hind legs (See Figure 1).

More sophistication is required as voltages increases and as application of the electrode becomes automated. Safety has been of utmost importance during experimentation and implementation of ES in New Zealand, Australia, the USA and Europe to the point that in some instances safety concerns have effectively prevented commercial adoption of the process.

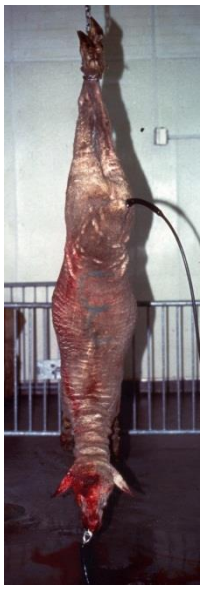

Figure 1. Electrical Stimulation of sheep carcass.

ELECTRICAL STIMULATION PARAMETERS

Harsham and Deatherage (1951) used voltages ranging from less than 50 to greater than 3000 V peak, the latter giving better current distribution throughout the beef cercasses. Many researchers have shown how both low and high voltage systems can benefit meat eating quality for both beef and sheep meat (Polidori et al., 1999; Shaw et al., 2005; Hopkins et al., 2006). A new generation of ES parameters was developed in Australia for both sheep/lambs and beef, based on pre-dressing medium-voltage stimulation, to avoid the danger associated with high-voltage (Toohey et al., 2008). This study used an optimised setting of 800 milliamperes (mA), varying voltage with a peak of 300 V, a pulse width of 0.5 milliseconds (ms) and a unipolar waveform. The stimulation treatment was applied for approximately 60 s with a frequency of 15 Hz. The results obtained in that study confirmed that ES effectively increased the rate of pH decline when the current is administered to wool on carcasses with no negative impact on any meat quality trait., with an improvement in tenderness determined 24 h after slaughtering.

Factors Affecting ΔpH

The rate of post mortem pH and temperature decline can significantly impact on the resulting tenderness of meat (van de Ven et al., 2014). For optimal eating quality sheep meat should reach pH 6 when the carcass temperature is between 18 and 35°C (Thompson et al., 2005). ES acts by accelerating the onset of rigor (pH 6.0) resulting in a higher temperature at which a carcass enters rigor (Hwang et al., 2003). The temperature at the point a carcass reaches pH 6.0 and enters rigor can be used to predict meat quality (Thompson et al., 2005). If the carcass temperature falls too fast before the onset of rigor then cold shortening may result, which can have adverse effects on meat tenderness (Tornberg, 1996).

The Asutralian Sheep Meat Eating Quality (SMEQ) program identified various temperature ranges for optimal eating quality depending on the market for the product (Toohey et al., 2008). It was concluded that the target temperature range to achieve pH 6.0 should be 18-25°C for short aged meat destined for the domestic market.

When muscles of freshly slaughtered animals are electrically stimulated, they contract. There is a concomitant increase in biochemical reactions in the

muscle cells leading to an accumulation of lactate resulting in an immediate drop in the muscle pH (ΔpH). The magnitude of ΔpH is governed by muscle fibre type, initial glycogen stores within the muscle, the electrical parameters (current, frequency, pulse shape, stimulation duration), muscle temperature, and the time after death at which ES is applied (Devine et al., 2014).

The increase in glycolytic rate can be explained by ES causing a reduction in the energy of activation, specifically the amount of energy necessary to start the reaction in excess of that already possessed by the molecules. If the energy of activation is high, the rate is low and vice versa. In addition, ΔpH is strongly affected by temperature, being faster at higher temperatures, so that an increase has a greater effect on ΔpH of stimulated muscles than that of unstimulated muscle. These changes are possibly a consequence of irreversible changes to ATPase activity that dictate the rate of ATP hydrolysis and therefore pH decline (Devine et al., 2014).

Frequency of ES

The higher is the pH, longer is the time for muscles of stimulated carcasses to reach pH 6.0; the frequency of the applied voltage is an important determining factor. At frequencies between 10 and 20 pulses/sec pH values are, respectively, 40 and 75% greater than tat 50 and 100 pulses/sec (Polidori et al., 1996). The frequency optimum of around 9-16 pulses/sec seems to hold for most muscles of sheep and beef carcasses. When considering such complex interactions, a clearcut assembly of the influences of stimulation parameters is not to be expected. Thus, with short stimulation periods, high frequencies (50 to 100 pulses/sec) give higher pH values than those produced by lower frequencies. If longer stimulation periods can be used (120 sec), then 9-16 pulses/sec give the highest pH. The lower frequencies produce a slightly lower peak tetanic tension than the higher frequencies but maintain their peak tension for a considerable longer time.

An advantage of lower stimulation frequencies is the lowered energy input. For example, at 14.28 pulses/sec, the energy input is only one-seventh of that at 100 pulses/sec; this significantly reduces heating at the electrode contacts and in the musculature (Chrystall & Devine, 1978). In an experiment based on the application of 60 Hz frequency ES on beef sides, Takahashi et al. (1984) found that this frequency produced very extensive fracturing with breaks appearing on average every 6 mm of fibre length. This treatment resulted in a very significant tenderizing relative to that observed in the unstimulated control sides.

TENDERIZATION MECHANISMS OF ELECTRICAL STIMULATION

Meat tenderness has been considered by many authors as the prime determinant of consumer satisfaction with meat purchase. Although the ultimate measure of tenderness or toughness lies with the consumer, objective assessments can be made with a wide variety of mechanical devices, because these devices can reliably indicate differences attributable to animal and processing factors (Destefanis et al., 2008). Meat tenderness-toughness depends on both the myofibrillar strength and the connective tissue strength. ES seems mainly to modify the myofibrillar strength, although a study suggests that ES could also have an impact on the connective tissue component (Mills et al., 1989).

The major improvement in tenderness of electrically stimulated meat was originally due to prevention of cold shortening, as above mentioned. However, ES also appears to improve tenderness above that which can be accounted for inhibition of cold shortening. In fact, ES generally improves tenderness even though no differences in sarcomere length may be evident between stimulated and unstimulated muscles (Uytterhaegen et al., 1992; Toohey et al., 2008; Polidori et al., 2016). Evidence suggests that ES may also benefit tenderness by causing the rapid release of lysosomal enzymes and/or by physical disruption of the electrically stimulated muscle fibres. The linkage between improved meat tenderness and physical disruption is plausible, as ES treatment has improved tenderness under circumstances where no cold shortening was evident. However, it is unclear whether it is the physical disruption per se that has caused the effect or whether the physical disruption facilitates ageing in other ways, such as enhancing proteolysis (Devine et al., 2014).

Lysosomal enzymes are known to have the ability to degrade the myofibrillar proteins under the high temperature and low pH conditions prevailing in post mortem muscle (Sorinmade et al., 1982). Release of the lysosomal enzymes plays an important role in meat tenderization following application of ES. The disruption of the lysosomal membranes with the release of the lysosomal enzymes appears to be responsible, at least in part, for the increased tenderness of electrically stimulated meat.

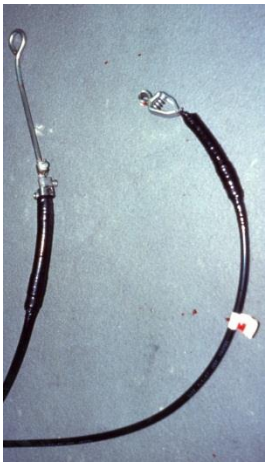

Figure 2. Contacts for ES: rectal probe (left) and clip for nostrils (right).

Sorinmade et al. (1982) presented ultrastructural evidence that ES causes contracture bands with superstretching of the myofibrils, resulting in the absence or presence of poorly defined A-bands, I-bands and Z-bands. This further substantiates the fact that physical disruption is another mechanisms whereby tenderization occurs as a consequence of ES.

ES accelerates activation of calpains and subsequent proteolysis of myofibrilar/cytoskeletal proteins, which results in improvement of meat tenderness (Lee et al., 2000) since the rate constants for the post mortem decline in calpain and for tenderization were similar, suggesting the loss of calpain activities is inversely related to tenderization. There are several possible explanations why ES might increase the activity of specific enzymes such as the calpains. It may be due to some intrinsic effect associated with the rapid pH decline, with a low pH at high temperatures, that affects the processes governing the activation and inactivation of the calcium dependent proteases, or it could be due to a flow-on effect associated with a significant increase in free calcium, which leads to activation of the calpains, especially μ-calpain (Devine et al., 2014).

Effects of ES on Different Meat Animals

ES causes an increase in the rate of *post mortem* glycolysis and prevents excessive cold shortening during *rigor* in common livestock species. Hwang et

al. (2003) described the three classical area by which ES is proposed to elicit changes in *post mortem* muscle:

1. Prevention of cold-induced shortening by ensuring *rigor mortis* occurs under optimal conditions;
2. Physical disruption of the muscle fibres;
3. Acceleration of proteolysis

Acceleration of proteolysis could be classified as a secondary effect mediated through the time-temperature-pH interactions, affecting factors such as enzyme stability and activity. ES of carcasses after slaughter is a process that can have a significant effect on meat tenderness, and for this reason it has been used for beef, pigs, deer, goats, sheep, cattle, buffalo, poultry, alpacas and donkeys (see Table 1).

The first study in which ES was used to hasten the *rigor mortis* process was conducted in 1951 by Harsham and Deatherage. These workers stimulated beef carcasses by attaching multiple electrodes on the surfaces and stimulating at 1700-3500 V and 50 pulses/sec. Their pH/time curves closely resemble those obtained in more recent works: They showed that ES helped to tenderise meat and suggested that this was due to release of catheptic enzymes during ES. No more was heard of the notion of ES of large meat animals until it was resurrected in New Zealand (Carse, 1973) for lambs and later for beef (Bendall, 1980). The review published by Hwang et al. (2003) summarize the biochemical and physical effects of ES on beef and sheep meat; the conclusions stated that ES can result in no or a detrimental effect on meat tenderness. Provided pre-slaughter animal status and chilling regime are taken into account when the total energy input from ES is decided, meat tenderness will be improved. However, ES does not improve inherently tender meat beyond baseline toughness.

High voltage ES (700 V, 1400 V peak, pulses 1 sec/on – 1 sec/off, 60 Hz) on buffalo carcasses resulted in a significantly more rapid pH fall in muscle *Longissimus dorsi thoracis* when compared to non stimulated control (Soares & Arêas, 1995). ES produced buffalo meat with better texture characteristics, and the final product from stimulated carcasses had superior quality compared to control group. The results obtained in this study indicated that that ES can be applied in buffalo slaughter, and results in a shorter period for the onset of *rigor mortis*.

ES has been used on broiler carcasses to accelerate the production of boneless meat by reducing or eliminating the need for the costly ageing process (Sams, 1999). ES systems using high amperages of 350 to 500 mA per bird induce such forceful contractions that the muscle not only exercises to accelerate ATP depletion, but tears itself. The physical disruption tenderize the meat as the *rigor mortis* acceleration from the exercising prevents toughening. The combination of these two mechanisms has generally made high amperage ES more effective at reducing the need for the ageing period and effective without combining it with other procedure. High amperage ES results in sufficient reduction in the toughening to produce meat deboned immediately after chilling (1.5 to 2 h *post mortem*) that would be considered slightly to moderate tender to consumers (Sams, 1999). Using the same amperage and pulsing that is effective on broilers, ES was not effective in reducing the need for ageing in turkeys (Owens & Sams, 1997) or ducks (Owens et al., 1997. Differences in muscle fibre type and metabolism (Walker et al., 1996) may account for the different response to ES among species.

A study conducted on 96 goats of similar age, weight, quality grade and yield grade were conducted by McKeith et al. (1979). Results obtained in this study indicated that ES improved tenderness of goat muscles and that ES can be performed at any of several stages during the slaughter-dressing sequence, Advantages for a particular site and for split *vs* unsplit carcasses were not apparent, thus meat packers can install ES equipment at any point in the slaughter-dressing sequence where space is available and safety of workmen is not compromised.

The first study in which ES was applied to Danish Landrace pigs was carried out by Hallund & Bendall (1965); the acceleration of pH fall after ES lasted during the whole course of the pH-time curves. Gigiel et al. (1984) demonstrated that ES produced more tender pork after conventional chilling of Large White x Landrace pigs, while Westervelt & Stouffer (1978) did not find improvement in tenderness of the *Longissimus* muscle obtained by electrically stimulated Yorkshire hogs. The Authors suggested that the unexplained mechanisms of response of porcine muscle *Longissimus* to ES may be similar to the cold-shortening characteristics of pork muscle which are only a tenth of those observed in the bovine and ovine species. A study conducted by Wiley et al. (1989) revealed that loin chops obtained from electrically stimulated hog carcasses were less tender than those from unstimulated carcasses. The updated knowledge about use of ES on pigs said that with optimum technical parameters ES is effective on pork, especially for some breeds; very stress-susceptible breeds such as *Pietrain* do not give good results (Devine et al.,

2014). ES cannot produce a PSE-like condition, because PSE in pork arises from severe myosin denaturation *pre rigor* and in worst cases a lot of drip is produced because myosin is a major muscle protein. Tenderization occurs via cytoskeletal denaturation *post rigor mortis* of smaller amounts (<10%) cytoskeletal proteins, therefore no extremes of drip thus no PSE.

A total of 14 female red deer were included in a study on the effects of low voltage carcass electrical stimulation on meat tenderness, colour stability and water-holding capacity (Wiklund et al., 2001). Carcasses were randomly allocated to either electrical stimulation treatment (90-95 V unipolar pulses, 7.5 ms duration, 15 Hz for a duration of 55 s) or no electrical stimulation. Compared to controls, ES increased the rate of muscle pH decline and produced lower shear forces at 1 day, 1 week and 3 weeks post-mortem, but these differences disappeared by 6 and 12 weeks post-mortem. This study showed no detrimental effects of using ES meat colour stability or drip loss.

Table 1. Studies which have measured the effects of ES in meat animals

Species	Voltage applied	Authors
Lambs	250	Carse, 1973
Lambs	3600	Chrystall & Hagyard, 1976
Pigs	110	Westervelt & Stouffer, 1978
Pigs	550	Wiley et al., 1989
Goats	100	McKeith et al., 1979
Beef	32	Taylor & Marshall, 1980
Beef	300	Smulders et al., 1986
Buffalo	700	Soares & Arêas, 1995
Turkey hens	570	Owens & Sams, 1997
Broiler	450	Owens & Sams, 1998
Deer	95	Wiklund et al., 2001
Alpaca	300	Smith et al., 2016
Donkeys	28	Polidori et al., 2016

In a study conducted on 50 huacaya alpacas (Smith et al., 2016), the use of a medium voltage (300 V) ES significantly reduced on muscle *Longissimus thoracis et lumborum* purge values by 3% and shear force at 5 and 10 days *post mortem* in both *Longissimus thoracis et lumborum* and in *Semimembranosus* muscles; consumers rated ES samples higher on tenderness, juiciness, flavour and overall rating. This study showed that ES of alpaca carcasses is recommended as it significantly improved meat quality

attributes and reduced the incidence of lean alpaca carcasses experiencing cold induced shortening.

The effects of early post mortem low voltage electrical stimulation (28 V, 60 Hz) on biochemical changes and on final tenderness in *Longissimus thoracis et lumborum* muscle from donkey carcasses was studied (Polidori et al., 2016). ES significantly accelerated the glycolytic process during the first hours post mortem, with a faster pH fall at 1, 3 and 6 h post mortem, and a reduction in ATP content at 3 and 6 h post mortem. Tenderness was significantly improved ($P < 0.05$) at 4 and 7 days post mortem by the application of ES.

Effects of ES on Meat Colour

ES is applied with the aim of ultimately improving meat tenderness, but there have been reported some minor effects such as ES-mediated meat colour changes. Meat colour is an important quality trait to monitor given consumer decisions at the pint of purchase are influenced by meat colour more than any other quality factor and consumers use the degree of discoloration as an indication of freshness (Mancini & Hunt, 2005). It seems unlikely that electricity on its own affects meat colour. The effect possibly arises because the process depletes the metabolites of surviving oxidative pathways in the muscle, or because the fast pH fall causes the muscle proteins from treated carcasses to approach their isoelectric point much sooner, thereby "opening up" the structure and easing oxygenation of myoglobin (Polidori et al., 1996). The latter explanation seems at least partially responsible because, although the cut surface from electrically stimulated sides develops a brighter red than those from control sides when exposed to the air at 12-20 h *post mortem*, by this time both electrically stimulated and control muscles would have attained their ultimate pH, the structure in both would be "open" and residual oxygen utilization of the same order (Lawrie, 1991).

In a study conducted by Toohey et al. (2008) in which was used a medium voltage (300 V, 15 Hz) on 40 stimulated lambs, compared to 40 control lambs, there was no significant difference between lightness L^*, redness a^* or yellowness b^* values in the two groups of animals. Similar results were found in a study conduced by Channon et al. (2005) where it was determined that use of ES had no effect on the meat colour of lambs.

A study in which the same voltage (300 V) has been used to stimulate 25 alpaca carcasses (Smith et al., 2016) found a significant difference ($P<0.05$) in lightness L^*, with meat samples from stimulated carcasses being lighter than

those from unstimulated carcasses. This increase in lightness was thought to be primarily due to an effect of the increased glycolysis and pH decline occurring due to ES. This trend in lightness agrees with other studies in which was investigated the effects of low and high voltage ES on lamb carcasses, with the result of an increase of L* values from the control of 28.0 to the value of 29.6 for low voltage and up to 31.4 for high voltage (Shaw et al., 2005).

Finally, a study performed on donkey carcasses electrically stimulated using low voltage (28 V, 60 Hz) found a significant improvement ($P<0.05$) in lightness L^* determined in meat from stimulated carcasses (35.4) compared to control group (33.2), while the difference in redness (a^*) and yellowness (b^*) values was not statistically significant (Polidori et al., 2016). This increase in lightness has been mainly attributed to the acceleration of the glycolytic process due to electrical stimulation, with the faster pH decline and ATP depletion occurred in stimulated donkey muscle.

CONCLUSION

ES is considered a valid method for accelerating the *post mortem* biochemical changes in muscle. Thus, full *rigor* is established in stimulated carcasses and the final pH is reached in their muscles within about 4 h from stimulation, compared to 15-20 h in unstimulated carcasses. Industrial application of this process to tenderize meat as well as facilitate the earlier processing and utilization of meat through normal distribution channels has made ES one of the most talked-about innovations in the meat industry. Advantages for the packer, retailer, purveyor and consumer exist due to the multiple benefits obtained when ES is used as an integral step in the process of converting live animals to meat and meat products. ES has become one of the most useful potential tools in meat technology, particularly in view of the increasing tendency in commercial practice to cool carcasses as soon as possible after slaughter.

The challenge for further development of ES systems is optimisation of the activation of the enzyme systems, possibly by chilling regimes to ensure *rigor mortis* close to 15°C, within the constraints of food safety concerns and bearing in mind the different fibre composition of muscles. In this sense a more targeted approach such as the use of local specific stimulation of certain muscle groups, susceptible to rapid chilling effects, may be more beneficial for improving tenderness.

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Research and Professional Experience:

1. Protein profile characterization of donkey milk.
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Professional Appointments:

- From November 1993 to October 2000: Researcher in Animal Husbandry in the Faculty of Veterinary Medicine, University of Camerino, Italy.
- From November 2000 to December 2005: Associate Professor in Animal Husbandry in the Faculty of Veterinary Medicine, University of Camerino, Italy.
- Since January 2006: Full Professor in Animal Nutrition in the School of Pharmacy, University of Camerino, Italy

Honors:

- From September 1995 to March 1996: Visiting scientist at the Muscle Biology Lab, University of Wisconsin, Madison, USA (six months period, Italian National Research Council grant).
- From August 1998 to June 1999: Visiting scientist at the Department of Food Science and Technology, University of Tennessee, Knoxville, USA (11 months period, North Atlantic Treaty Organization grant).
- From January 2008 to December 2010: Member of the Editorial Board of the journal Small Ruminant Research, Elsevier Publisher, The Netherlands.

- Since March 2009: Member of Expert database of EFSA (European Food Safety Agency), Parma, Italy.
- Since 2011**:** Member of the Editorial Board of the Open Journal of Animal Science, SCIRP Publisher, USA.
- Since 2011: Member of the Editorial Board of the Journal of Food Research, Canadian Centre of Science and Education, Canada.
- Since 2013: Member of the Editorial Board of the International Journal of Child Health and Nutrition, LifeScience Global, Canada.

Peer Reviewed Publications Last 3 Years:

1. **Use of Donkey Milk in Children with Cow's Milk Protein Allergy.**
   Polidori P., Vincenzetti S.
   Foods, 2013, 2, 151-159, doi: 10.3390/foods2020151
2. **Meat Quality in Donkey Foals.**
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- ***Oleic Acid in Milk of Different Mammalian Species.***
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