ELECTRICAL STIMULATION DEVELOPMENTS IN NEW ZEALAND

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INTRODUCTION

Electrical stimulation of carcasses for the improvement of meat tenderness, although patented by Harsham and Deatherage (1951), lay dormant as a process until its rediscovery and development by New Zealand researchers. Research workers in other countries have subsequently devoted much time to its further development. It is not surprising that the initial rediscovery and development occurred in New Zealand, as the Meat Industry Research Institute of New Zealand (MIRINZ), since its inception, has directed its research efforts to understanding the relationship between cold and tenderness. The discovery of the cold shortening phenomenon (Locker & Hagyard, 1963), the realization of its importance to toughness in lambs (Marsh et al., 1968) and beef (Davey, 1969, 1971) and the processing procedures to avoid cold shortening (Locker et al., 1975) were all discovered in New Zealand for the same reasons. An average works in New Zealand slaughters over 10,000 lambs per day in season, some exceed 20,000 per day, and because of this high throughput, efficient freezing systems were developed with minimal pre-freezing delays.

Prior to the advent of electrical stimulation, lamb carcasses frozen soon after slaughter could be extremely tough. If the lamb carcasses are held above 10°C until rigor mortis is achieved without shortening, they are 'conditioned' and can be frozen without toughening. A period of 'aging' can be added after conditioning to further improve tenderness. This is the basis of "Conditioning and Aging" used to ensure tender lamb for selected markets (Locker et al., 1975). Too much time and space would be needed to condition and age the entire 26 million lamb kill.

Various alternatives were considered which would introduce minimal time delays into the existing process and yet ensure tender meat. Electrical stimulation of beef neck muscles showed that the time course of rigor could be dramatically altered (MIRINZ, 1972). Extension of studies to lamb showed that stimulating carcasses at 30 minutes post mortem for a 30 minute period with a 250 volt pulsed DC current reduced the time for muscle pH to reach 6.0 from 16 hours to a mere 3 (Carse, 1973). From this stage developments were progressive and included varied voltages of different waveform, ranging from highly modified capacitive discharge electric fence units to specially built sinusoidal pulse generators. The early prototype stimulation tunnel was located in the bleeding area on one chain of a large works. The woolly carcasses suspended by a shackle on their right legs passed across a live electrode (MIRINZ, 1973). Differences in tenderness of left and right legs of early frozen stimulated lamb legs (MIRINZ, 1974) required development of a system to ensure electrical contact through both hind legs. Other developments were necessary to overcome burning and scorching of wool and pelt. The high voltage (3600 volt peak) system employed was designed to overcome the contact resistance, and the voltage then collapsed so that a current of 2 amp peak flowed through the carcass from shoulder to hind legs (Chrystall & Hagyard, 1975). The results of these early studies showed that by stimulating within 5 minutes of slaughter for a 45 second period, the carcasses could be moved into a freezer at 2 hours post mortem and frozen at a moderate freezing rate, and then, even if cooked from a frozen state, be acceptably tender. Problems arising from early stiffness of carcasses after stimulation and space limitations in some works meant that an alternative was necessary. Stimulation of the dressed carcass was reinvestigated. Because the practical systems had to be able to rapidly 'condition' the muscles and allow early freezing or chilling without causing toughness, laboratory studies centered on those factors which could influence the rate of glycolysis. These included electrical parameters (voltage, frequency, duration), method of application (direct or indirect), delay and temperature. In these studies the effects of stimulation have been largely evaluated by pH changes in muscle. Electrical stimulation hastens the processes of rigor in two stages, a drop in pH during stimulation (ΔpH), followed by an increase in rate of pH fall ($\frac{dpH}{dt}$). The magnitude of ΔpH is dependent on stimulation parameters, but $\frac{dph}{dt}$ seems to be largely independent of these.

Regardless of stimulation parameters, the $\frac{dph}{dt}$ in most muscles is increased 1.5 to 2 times that of non-stimulated muscles (Chrystall & Devine, 1978). The rate change may not be noticed in some muscles, since vigorous muscle movements during slaughter may effectively be producing the same effect (Devine et al., 1979; Chrystall et al., 1980a,b). The insensitivity of $\frac{dph}{dt}$ to variation in stimulation conditions means that it is the variation in ΔpH that has the major impact on time for muscles to become insensitive to cold, i.e. fall below pH 6.0

(Bendall, 1975). For example, at a constant 35°C the pH of non-stimulated beef sternomandibularis falls at 0.18 pH units per hour, taking 6 hours to reach pH 6.0, whereas in stimulated muscles the rate is 0.3 pH units per hour. A difference in ΔpH of 0.3 pH units is equivalent to one hour saving in the time to reach pH 6.0. Under falling temperature conditions Δ pH will have a proportionately greater contribution to rigor acceleration.

ELECTRICAL PARAMETERS

Voltage and Current: Although the current flowing through the muscles is the important factor, most studies have referred to the applied voltages, even with very varied electrical contact. In general, higher voltages increase the effectiveness of stimulation by giving a larger ΔpH, and also increase the uniformity of reaction throughout the muscles (Chrystall & Devine, 1978; Chrystall et al., 1980; Bouton et al., 1980). It is considered to be the most important factor when stimulating beef carcasses or sides (Bendall et al., 1976; Bendall, 1980; Bouton et al., 1980; Savell et al., 1978b). Tenderness changes parallel the pH changes. Lambs stimulated at 30 minutes post mortem with 14.3 pulses derived from 800v (RMS) are more tender than those stimulated at the same frequency but with pulses derived from 400v (RMS) when early chilling and freezing is imposed at 2 hours post mortem (Chrystall, 1978). The pulses derived from 800v (RMS) give the same 2 amp peak current through the dressed carcasses as was given by the 3600 peak volt system used for woolly carcasses.

Lower voltages result in a lower ΔpH and therefore are less satisfactory when carcasses are subjected to early and rapid chilling or freezing conditions, but will be satisfactory when delays are longer or chilling rates less rapid (Bouton et al., 1978; Fabiansson et al., 1979; Nilsson et al., 1979).

Frequency: At any given stimulation period and voltage, pulse frequency has a considerable effect on the magnitude of ΔpH. With beef sternomandibularis muscles the maximum Δ pH values (>0.7 pH units in a 120 second period) were achieved with between 5 and 16.6 pulses/second (Chrystall & Devine, 1978). This has been confirmed for a longissimus dorsi (LD) of beef by Bouton et al. (1980), but their results obtained using lower voltages increased in a stepwise manner show that the semimembranosus muscle behaves differently. Bendall et al. (1976) felt that the important factor in hastening rigor was the number of pulses, but our results (Chrystall & Devine, 1978) show that the relationship is complex since ΔpH increased markedly with stimulation period, but decreased with pulse frequencies above 20 pulses per second. The 14.28 pulses per second used in our system are of alternating polarity and are derived by simple electronic switching of the 50 Hz AC mains supply. Carcasses or sides stimulated with this frequency give a large contraction when the power is turned on, but then remain in a contracted, trembling state until either exhaustion occurs or the current is turned off. The lack of continual movement is a considerable advantage in any mechanical system. The alternating polarity pulses, although only slightly superior in terms of ΔpH, show a marked superiority in tenderness for lambs when they are used instead of a unidirectional pulse train of the same frequency (MIRINZ, 1977).

DELAY AND TEMPERATURE

In a practical situation when dressed carcasses are to be stimulated, delay from slaughter although unavoidable may introduce three problems. Firstly, if nervous stimulation is involved, neural death would place limitations on the allowable length of delay before stimulation. Our results (Chrystall et al. 1980a, b) show that stimulation of lambs via the nervous system was ineffective at 30 minutes post mortem. At these times post mortem direct stimulation is the only viable alternative. Secondly, with delay the muscle pH falls and this affects the magnitude of the ΔpH which can be expected (Chrystall & Devine, 1978). Thirdly, and probably most importantly in a practical situation, muscle temperature falls. Glycolysis has a high temperature coefficient (Bendall, 1977; Jeacocke, 1977) and therefore any temperature change could markedly affect rates of pH fall during and after stimulation.

ΔpH is reduced with lower temperatures. If we consider the ΔpH produced whilst the muscle is maintaining near maximum tension, for up to 30 seconds when stimulation is with 14.28 pulses per second (Chrystall & Devine, 1978), the energy of activation is 97 kJ/mol. This is the same as that for the calcium-activated actomyosin ATPase (Bendall, 1969, 1975; Jeacocke, 1977), indicating that maximal muscle activation is being achieved. If we consider the ΔpH over the full 120 second stimulation, then the apparent energy of activation with 14.28 pulses per second falls to about 43 kJ/mol due to muscle exhaustion. Since tension maintenance varies with frequency but is greatest at about 14 pulses per second, the apparent energy of activation may also vary. Our results for $\frac{dpH}{dt}$ in non-stimulated beef neck muscles give an energy of activation of about 50 kJ/mol, slightly higher than values of Jeacocke (1977), but for stimulated muscles the value is even higher, about 70 kJ/mol. The large increase suggests a change in anaerobic glycolytic rate controlling steps which may be related to some irreversible enzyme binding to actin filaments (Clarke et al., 1980) or to mitochondrial changes (Devine, 1976).

It is clear that with the high temperature coefficients and early onset of neural death, carcasses or sides should be stimulated as early as possible. This is especially true for small animals such as lambs. Although a stimulation period of 45 seconds within 5 minutes of slaughter is sufficient to ensure acceptable tenderness in early frozen lamb, twice the period is required to get the same effect 25 minutes later (Chrystall, 1978). Beef, because of its larger bulk, takes longer for temperatures to fall below critical levels, at least 40 minutes (Bendall, 1980; Davey et al., 1976) or 60 minutes (Gilbert - pers. comm.).

DURATION OF STIMULATION

Although Carse (1973) used a 30 minute stimulation period, it was quickly realized that most of the effect occurred within the first five minutes. The change in $\frac{dph}{dt}$ requires only a very short stimulation period, but to obtain maximum ΔpH about 120 seconds are required (Chrystall & Devine, 1978). If only a very short stimulation period is possible there is a slight indication that higher frequencies are slightly better than the 14.28 pulses per second used in our systems. However, since we require the maximum possible reduction in time for rigor to be achieved so that freezing can take place early, stimulation is generally for 90 or 120 seconds with the lower, more effective frequencies to give the maximum possible ΔpH.

STRUCTURAL DAMAGE AND AGING

Prevention of cold shortening is the main mechanism by which tenderness improvement becomes evident after electrical stimulation (Chrystall & Hagyard, 1976; Davey et al., 1976; George et al., 1980; Bouton et al., 1980). Also because rigor is achieved much earlier than normal, aging can commence at the higher muscle temperatures and is therefore more rapid. Stimulated and non-stimulated beef sternomandibularis muscles are, however, of equal tenderness if they are cooked immediately they pass into rigor and aging changes are avoided (Devine & Chrystall - unpublished observations).

Some researchers consider that electrical stimulation has a tenderizing effect other than that of avoiding cold shortening (Savell et al., 1977; Vandekerckhove and Demeyer, 1978). A factor which could give rise to an apparent increase in aging rate is that unstimulated muscles can cold shorten during rapid chilling, and shortened meat does not age completely (Davey et al., 1967). The effect is clearly illustrated in the LD muscles of rapidly chilled beef. These muscles from stimulated sides aged satisfactorily, whereas those from unstimulated sides remained intractably tough (Davey et al., 1976).

Our results, in contrast to those of Savel et al. (1978a), show that although electrically stimulated lamb and beef LD muscles show supercontracted fibres, the proportion is very low, 2 to 5%. Cold shortened muscle also shows supercontracted fibres (Marsh et al., 1974), but only when the condition predominates is there any increase in tenderness. A larger proportion of fibres show protein precipitation similar to that seen in PSE pigs (Bendall & Wismer-Pedersen, 1962), but contrary to expectations there is no evidence of a PSE condition in either stimulated lamb or beef (Bendall, 1980).

If structural damage was the main mechanism by which stimulation improved tenderness, it is unlikely that tenderness would be influenced by freezing (Chrystall, 1978) or chilling rate (George et al., 1980).

Electrical stimulation, accepted by processing companies throughout the world, has been successfully tested under a wide variety of conditions, ranging from the low voltage rectal probe system (Bouton et al., 1978) through to the high voltage system used for stimulation of woolly lamb carcasses soon after slaughter (Chrystall & Hagyard, 1975). In most situations the early onset of rigor means aging commences earlier and progresses further under mild chilling conditions. Where early and rapid freezing or chilling takes place, the stimulation conditions must be near optimal if an acceptable level of tenderness is to be achieved. Mere avoidance of cold shortening is not enough to ensure a tender product when frozen lamb is cooked without prior slow thawing (Marsh et al., 1968), as thaw shortening must be eliminated also, requiring almost complete conditioning before freezing commences. The New Zealand experience with lamb stimulation has shown that an acceptable level of tenderness can be achieved when lambs are stimulated at 14.28 pulses per second at 2 amp peak current, 800v (RMS) for 90 seconds, not later than 30 minutes post mortem. The carcasses must dwell at not less that $6^{o}C$ for at least 90 minutes to allow completion of rigor before freezing.

Electrical stimulation obviously works, but full realization of its potential is up to the user.

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