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Variation in the response to manipulation of *post-mortem* glycolysis in beef muscles by low-voltage electrical stimulation and conditioning temperature

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Abstract

The aim of this study was to investigate how manipulation of glycolytic rate by *post-mortem* processing conditions influences quality of aged beef of two bovine muscles of different physiological character, *longissimus dorsi* (LD) and *adductor* (AD). *Post-mortem* glycolysis was manipulated by low-voltage electrical stimulation (LV-ES) of half carcasses and by chilling rate of the muscles. Multivariate statistical analysis was used to visualise the data, while ANOVA was used to identify significant effects and interactions. As expected there was a significant effect of LV-ES on the pH decline in the first hours *post-mortem* in both muscles. Moreover, significant effects of LV-ES on WB shear force measured 2 and 8 days after slaughter were observed for LD at both chilling temperatures, while for AD no effect on WB shear force was observed. Furthermore, the results revealed a large individual variation in the response of LV-ES on both pH decline and WB shear force, and this variation did not always correlate for the two responses. Some animals showed no response of LV-ES on pH decline, but still had an improved WB shear force, and vice versa. The results from this study indicate that there probably are other mechanisms than accelerated pH decline and prevention of cold-shortening, by which LV-ES can affect meat tenderness.

Keywords: Low-voltage electrical stimulation; *Post-mortem* glycolysis; Warner-Bratzler shear force; pH decline; *Longissimus dorsi*; *Adductor*

1. Introduction

In recent years consumers have become more aware of the high variability and inconsistency of beef product quality (Miller, Huffman, Gilbert, Hamman, & Ramsey, 1995). A large and significant variability in aged beef quality (i.e. tenderness and juiciness) has been documented, both between slaughter animals and between abattoirs (Morgan et al., 1991; Hildrum & Tornberg, 1998). According to a US study, 50% of consumers rated tenderness to be the most important attribute of beef eating quality (Miller et al., 1995). Thus, a large variation in aged beef tenderness can have a serious economic impact on the meat industry, since tenderness is a critical factor determining the consumer's acceptance of meat.

Final tenderness of meat is affected by the rate of *post-mortem* glycolysis in the muscles (Marsh, Lochner, Takahashi, & Kragness, 1981; O'Halloran, Troy, & Buckley, 1997). Thus, there is a need for techniques that can alter the *post-mortem* glycolysis rate in order to improve the end quality. *Post-mortem* glycolysis is influenced by several parameters, such as hereditary factors, feeding and stress before slaughter, and there are several ways in which

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post-mortem glycolysis can be manipulated. One is by altering the conditioning temperature, and thereby the chilling rate of the carcass, however this manipulation is very limited due to hygienic reasons. Moreover, different feeds and feeding regimes may also affect *post-mortem* glycolysis and final pH of the muscles by manipulation of glycogen levels at the time of slaughter (Andersen, Oksbjerg, Young, & Therkildsen, 2005). Another way of manipulating *post-mortem* glycolysis is by performing electrical stimulation (ES) of the carcass immediately after slaughter, which has found widespread use in the last two decades in the meat industry.

Post-mortem ES is a common method used to accelerate the depletion of the energy reserves in the muscles, thereby decreasing the risk of cold-shortening. There are several studies which report improved tenderness in beef when high-voltage electrical stimulation (HV-ES) was used (Elgasim, Kennick, McGill, Rock, & Soeldner, 1981; Gariepy, Amiot, Pommier, Flipot, & Girard, 1992; Marsh, Ringkob, Russell, Swartz, & Pagel, 1987). Due to installation costs and the safety for the operators, low-voltage electrical stimulation (LV-ES; voltage < 100 V), is frequently used in many countries instead of HV-ES. Some studies report that also LV-ES improves tenderness (Aalhus, Jones, Lutz, Best, & Robertson, 1994; Taylor & Marshall, 1980), but that the treatment should be applied within a short time after slaughter to be efficient (Chrystall, Devine, & Davey, 1980). Other studies report small or no effects (Rødbotten, Lea, & Hildrum, 2001), and even negative effects of LV-ES have been reported (Unruh, Kastner, Kropf, Dikeman, & Hunt, 1986). Several studies have shown that ES imposes risks of under- or over-stimulation of the carcasses and can result in quality deterioration, such as colour defects, tough meat, increased drip-loss and diminished shelf life, rather than improvement of quality (Hildrum, Solvang, Nilsen, Froystein, & Berg, 1999; Hwang, Devine, & Hopkins, 2003). Additionally, it has been reported that different muscles on the same carcass may respond differently to stimulation (Bendall, Ketteridge, & George, 1976; Devine, Ellery, & Averill, 1984).

Although LV-ES of carcasses is in widespread use to enhance meat tenderness, a large variation in beef tenderness have been observed when used under industrial conditions (Hildrum et al., 1999). Because LV-ES is implemented in the meat industry as a measure to guarantee meat tenderness, a uniform effect in all carcasses is needed.

In the present study individual responses to manipulation of glycolysis by LV-ES, conditioning temperature, and aging time on quality variables were investigated in two bovine muscles, *longissimus dorsi* (LD) and *adductor* (AD). A particular focus was to evaluate the animal to animal variation in the response to tenderness development and the rate of glycolysis. Both classical ANOVA and multivariate statistical analyses were used to visualise and validate the results.

2. Materials and methods

2.1. Animals

On the day of slaughter, the animals were transported 55 km (approx. 40 min) on a commercial vehicle and lairaged in single file boxes (individual pens) for 1–2 h at the abattoir prior to slaughter. Twenty-four NRF (Norwegian Red) bulls culled from a performance test station for young bulls (GENO Breeding and AI) were used in this experiment. The animals (12–14 months of age) were slaughtered in five batches in 2005 and 2006 at a commercial abattoir. The advantage of using bulls from a performance test station is standardised preslaughter environment i.e. feeding, management conditions and transport. Carcass grading for conformation and fatness were recorded according to the EUROP system. Between 30 and 90 min after captive bolt stunning and exsanguination, the right or left side (alternating) of the split carcasses were subjected to LV-ES.

2.2. Electrical stimulation and sample preparation

For the ES treatment, an adjustable M-300 HS Special stimulation apparatus (Norsystem AS) was used with the positive pole placed deeply in the ventral neck muscles (at the first and second cervical vertebrae; C_1–C_2) and the negative pole attached directly to the Achilles tendon. The opposite side served as a non-stimulated control (NES). The following LV-ES parameters were applied: Square-wave, unidirectional pulses of 8 ms duration were delivered at 14.5 pulses/s (Hz). The total stimulation period was 40 s, including a gradual increase from 0 to 95 V for 8 s (to prevent violent initial contractions that could otherwise cause the split carcass half to fall down) and then full stimulation at 95 V (peak) for 32 s. An instrument recording the applied current and voltage 1000 times per second summarised the total stimulation effect (W s) applied to each carcass. The stimulation response was judged visually using a 1–5 scale, where 1 indicates no or very slight contraction and 5 designates strong contractions with the side curling laterally to a curved position and the thoracic limb lifted well above the horizontal level.

Following weighing and classification of the carcasses (approx. 20 min post-ES), 40 cm of the LD (*thoracis et lumborum*) muscle (from 15 cm anterior to 25 cm posterior to the 11th vertebra) was removed from both carcass halves. The LD muscle was divided and assigned to various measurements and treatments as indicated in Fig. 1a. Additionally, the AD muscle was excised from both halves of seven carcasses in one of the slaughter batches, and treated according to a similar scheme of measurements and treatments (Fig. 1b). Muscle portions used for WB shear force, pH, and sarcomere length measurements at 2 and 8 days *post-mortem* were vacuum-packed in polyethylene bags, while the remaining muscle portions used for pH measurements up until 24 h post-ES were placed in similar bags