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Mobile abattoir versus conventional slaughterhouse—Impact on stress parameters and meat quality characteristics in Norwegian lambs

Marit Skog Eriksen[a,*], Rune Rødbotten[b], Ann Margaret Grøndahl[c], Mari Friestad[a], Inger Lise Andersen[a], Cecilia M. Mejdell[c]

[a] Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences, Arboretveien 6, PO Box 5003, 1432 Ås, Norway
[b] Nofima, PO Box 210, NO-1431 Ås, Norway
[c] Department of Health Surveillance, Norwegian Veterinary Institute, PO Box 750 Sentrum, 0106 Oslo, Norway

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ABSTRACT

The aim of the present study was to investigate possible differences in certain stress parameters and meat quality characteristics between Norwegian lambs slaughtered at a mobile abattoir (at two different localities) versus lambs slaughtered at a conventional, stationary slaughterhouse. Lambs slaughtered at the conventional slaughterhouse had higher serum cortisol levels than lambs slaughtered at a mobile abattoir ($P < 0.001$). Also blood glucose values were significantly lower at one of the two mobile slaughter localities compared to the stationary abattoir ($P < 0.001$). Animals at the conventional slaughterhouse displayed a higher frequency of vocalizations ($P < 0.01$) and showed more aggressive behaviour than lambs at the mobile slaughterhouse ($P < 0.01$). It was demonstrated that meat from lambs slaughtered at the mobile slaughterhouse had lower ultimate pH ($P < 0.001$). Also, meat from one of the mobile slaughter locations was more tender (having a lower Warner Bratzler shear force value, WB), compared to meat from the lambs slaughtered at the conventional abattoir ($P < 0.05$). Furthermore, some relationships between stress indicators and meat quality were demonstrated. WB was positively correlated to serum cortisol level ($r = 0.39$, $P < 0.05$). There was a positive correlation between serum cortisol level and the incidence of aggressive interactions ($r = 0.47$, $P < 0.05$). The frequency of aggressive interactions was positively correlated to number of vocalizations ($r = 0.73$, $P < 0.01$) and also muscle pH ($r = 0.66$, $P < 0.05$). Finally, the frequency of aggressive behaviours was negatively correlated to blood glucose levels ($r = 0.46$, $P < 0.05$).

1. Introduction

Animals have been slaughtered by humans since ancient times. Although recent attention has focused on diminishing animal pain and suffering, most production animals will experience some level of stress prior to slaughter. They are subjected to diverse challenges, including increased handling and human contact, transportation, loading and lairage, novel and unfamiliar environments, food and water deprivation, alterations in weather conditions and also changes in social structure through separation, mixing and crowding (Van Putten and Elshof, 1978; Shaw and Tume, 1992; Hemsworth and Coleman, 1998; Knowles, 1998; Terlouw, 2005; Ferguson and Warner, 2008; Miranda-de la Lama et al., 2010). As a consequence, the animals may experience fear, dehydration and hunger, physical injury and fatigue, and these events may ultimately have deleterious impacts on animal health and compromise animal

* Corresponding author. Tel.: +47 6496 5169; fax: +47 6496 5101.
E-mail address: marit-skog.eriksen@umb.no (M.S. Eriksen).

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welfare (Ferguson and Warner, 2008; Adenkola and Ayo, 2010).

The extent of the detriments is suggested to be related to the type, duration and intensity of the individual pre-slaughter challenges, and the animals' vulnerability (Ferguson et al., 2001). Exposing an animal to stressors will initiate a characteristic cascade of reactions in the organism, with activation of the nervous sympathetic-adrenomedullary system and the hypothalamic–pituitary–adrenocortical axis, causing an increase in levels of catecholamines and glucocorticoids, respectively (Chrousos, 1998). Apparent physiological changes comprise tachycardia, enhanced respiration rate, elevated body temperature and redistribution of visceral blood volume towards skeletal musculature and the brain. Several behavioural changes may also be evident, for example urination and defecation, increased alertness and enhanced vocalization rates, immobilization or escape attempts, and altered aggression (Chrousos, 1998; Steckler, 2005). Moreover, the quality of the meat can be negatively influenced in the final phases of an animal's life, if the environmental factors are unfavourable (Ferguson and Warner, 2008; Ekiz et al., 2010).

Meat quality is not a single, definite property, but rather a sum of several interacting parameters. For the majority of consumers tenderness is the most influential although juiciness, flavour and colour are important as well (Martinez-Cerezo et al., 2005). Stress prior to slaughter can affect the eating quality of the muscles. Lambs which were exercised for 15 min immediately before slaughter had significantly higher ultimate pH in their muscles compared with none-exercised animals (Warner et al., 2005). Other studies have shown that extensive stress may even give elevated pH values for lambs which had been allowed to rest for 3 days before slaughter (Devine et al., 2006). At slaughter the blood circulation stops and glycogen in the muscles is converted to lactic acid. For normal carcasses the pH value will decrease to approximately 5.5. However, ruminants which have been exposed to stress or increased muscle activity pre-slaughter will have depleted glycogen pools in the muscles. Meat from these carcasses may thus have higher ultimate pH. The relationship between meat tenderness and final pH follows a curvilinear pattern where the toughest samples usually have values around 6.0 (Watanabe et al., 1996). Although meat with pH values above 6.3 generally is tender, such samples have short shelf life and are not desirable.

Temperature in the early post mortem period interacts with muscle pH and highly influences the proteolytic enzymes. The calpain system, which is recognized as the main tenderizing enzymes, has highest activity at high temperature and high pH (Maddock et al., 2005). Half a century ago Locker and Hagyard (1963) performed their classical experiment which showed the effect of muscle temperature at the time of rigor onset. Both high and low temperature will induce a severe contraction and subsequent toughening of the meat, while 15 °C has been identified as the optimal muscle temperature at rigor. The time from slaughter to rigor varies among species, but 6–12 h is typical for lamb carcasses which not have been electrically stimulated.

At present, animal production in Europe is undergoing progressive restructuring, in that the number of farms is reduced, farms become more specialized and herd sizes are increasing. Likewise, the slaughter industry is subjected to organizational adjustment, leading to fewer, but larger slaughterhouses. However, many farms are still situated in remote locations, hence entailing long-distance transport of live animals. Among the different steps and processes involved in the pre-slaughter logistic chain from farm to abattoir, transport is considered to constitute a major stressor (Tarrant, 1990; Lambert et al., 1998). In this context, mobile abattoirs have been suggested to represent an alternative to alleviate animal welfare problems caused by transportation procedures and lairage at slaughterhouses. Such abattoirs denote complete systems applied for the slaughter of livestock that are entirely mobile so that they can be moved between different locations. Prototypes of mobile abattoirs have been developed and approved in several countries, among them Britain, the USA, Canada, Sweden and Norway. Mobile abattoirs may also be favourable from the consumers' state of view, since the welfare of farm animals is a growing public concern and an increasing number of consumers are requesting meat that is locally produced and originates from animals that are humanely raised and slaughtered. Whether or not mobile abattoirs are preferable options for producers is contingent upon the cost and benefits linked to such a system, and also whether they are favourable from a practical perspective. However, although there are several benefits related to application of mobile abattoirs, several elements have been reported to be challenging in these systems. A sufficiently rapid and even cooling of carcasses, and also availability of pure water supplies, is vital to food hygiene (Benefalk et al., 2002). Stunning before slaughter, especially in some species, bleeding and the development of suitable equipment are also found to be more problematic in mobile abattoirs. Also, a mobile abattoir has reduced capacity compared to a regular slaughterhouse, and may be more vulnerable to technical failure or replacement of personnel. In addition, animals often have to be transported for short periods of time. Some of these are factors that may put animal welfare at risk. Animal welfare concerns establish that every effort should be made to minimize stress during the pre-slaughter phase. In addition, there are sound economic reasons why stress prior to slaughter should be diminished, given the substantial evidence that stress may contribute to depreciated meat quality. It is commonly argued that application of mobile abattoirs would involve less stress to the animals to be slaughtered, thus improving animal welfare and enhancing meat quality. However, this topic has received relatively little scientific attention. To a large extent, the use of mobile abattoirs allows slaughter animals to be surrounded by familiar conspecifics, handled by acquainted people in their home environments, without significant transportation prior to slaughter. Accordingly, the aim of the present study was to identify possible differences in certain stress parameters and meat quality characteristics between Norwegian lambs slaughtered at a mobile abattoir versus lambs slaughtered at a conventional slaughterhouse.

2. Materials and methods

The present study was carried out in Norway during autumn 2011. Two of the days the registrations were made at a mobile abattoir at two different locations (Østfold and Hordaland), whereas the third day the observations were made at a conventional, stationary slaughterhouse (Akershus). Several physiological, behavioural and meat quality parameters were collected from more than 200 lambs and sheep. However, due to capacity reasons all reported variables were obtained from 36 animals only, which means 12 lambs from each location. Cortisol content was measured on 154 sheep and was the single parameter which was obtained from the highest number of samples. Both male and female lambs, of different breeds, were included in the study. All 36 lambs subjected to textural analysis were from the NKS-breed (Norsk Kvit Sau). They were approximately 6 months old at slaughter. Behavioural observations were obtained while the animals were waiting in holding pens before slaughter. The stun quality was evaluated according to EFSA (2004).

2.1. Process description at the mobile abattoir

The sheep were the farm's own animals or originated from a nearby farm, transported by the farmer for approximately 10–20 min. Prior to slaughter, the lambs were clipped a 5 cm broad stripe along the midline from throat to udder/scrotum. Most animals were otherwise unsheared. They were kept in small, familiar groups in a waiting pen or on the utility trailer. The owner took one and one lamb out of the trailer and left it to the operator who led the animal to the place where it was immobilized between his knees and then stunned with a penetrating captive bolt. Top of head position was used except for 8 horned individuals who were shot in the poll position. After collapse it was shackled and hoisted into the mobile unit where it was bled (gash sticking). After bleeding the animal was skinned and eviscerated. Slaughter capacity was 8–9 lambs per hour.

2.2. Process description at the stationary abattoir

At the stationary abattoir the animals had been transported for 2–5 h and lairaged overnight in large holding pens in a barn close to the abattoir. The next morning they were transported approximately 5 min from the barn and upon arrival they were redistributed in groups with familiar and unfamiliar individuals. The animals were continually regrouped and moved closer to the place to be stunned. The animals were led through a raceway and mechanically carried to the stunning area in a single file in a V-shaped restrained conveyor. The animals were electrically stunned (220 V, 50 Hz, 1.0 A for 4 s using manually operated tongs), followed by full throat sticking before shackling. They were then left to bleed out, before further processing. Slaughter capacity was approximately 180 lambs per hour.

2.3. Physiological parameters

During the first seconds of bleeding, blood samples were collected. Glucose ($N=73$) was determined by applying a portable hand-held glucose meter (FreeStyle Mini™ Abbott, TheraSense Inc., Alameda, CA, USA). A small drop of blood was placed on a test strip and the glucose level was assessed instantly. In addition, blood was collected into siliconized evacuated 8 ml serum separation tubes (Terumo® VENOSAFE™), stored in a refrigerator overnight and centrifuged at 3000g for 10 min at 4 °C. Serum was then separated and frozen (−20 °C) until analysis of cortisol ($N=154$). Cortisol was measured by Electrochemiluminescens immunoassay (ECLIA) on Roche E 170 Modul (Roche Diagnostics, Mannheim, Germany). The sensitivity of the cortisol assay was 1 nmol/l. Total coefficient of variation was less than 2% in the actual measuring range.

Table 1
Descriptions of postures and activities recorded during observations of the lambs while kept in waiting pens.

Behaviour	Description
Vocalise	Bleating
Flee	Trying to escape
Fall	Falling involuntarily, so that other parts than the legs touch the surface
Push[a]	Nose, side of head or shoulder forcible applied to another animal
Butt[a]	Top of head forcible applied to another animal
Mount[a]	Jumping up on another animals back
Defecate	Defecating
Urinate	Urinating
Ruminate	Chewing cud while standing or lying
Explore	Sniffing and licking pen floor and fittings
Stand inactive	Standing still, doing nothing else

[a] Push, butt and mount were grouped as aggressive behaviour.

2.4. Behavioural observations

Behavioural parameters were recorded by instantaneous video scan sampling at 5 min intervals of 20 randomly selected animals at each location. All incidents of vocalizations, fleeing attempts, falling, urination, defecation and agonistic interactions were recorded continuously. The behaviours are described in Table 1. At the mobile abattoir, lambs were observed while they were waiting in holding pens or at the trailer before being slaughtered, and also when they were stunned and bled. The animals were also observed when they were led from their waiting area to the site to be stunned, and their resistance while being led was scored based on a scale from 1 to 4 (1 No resistance, is easily led; 2 Mild resistance, is quite easily led, but shows attempts to stop; 3 Medium resistance, can be led, but are more rigid, walk with stiff limbs and stops several times; 4 Substantial resistance, is difficult to lead, shows escape attempts and the leader is losing grip of the animal one or several times). At the stationary abattoir lambs were observed while they were waiting in holding pens before being slaughtered. The stun quality was evaluated according to criteria given by European Food Safety Authority (AHAW/04-027), and the time from stun to stick was recorded. At the mobile abattoir, using captive bolt, the stun quality was evaluated according to the following criteria; instant collapse, initial tonic seizure followed by a clonic phase, no rhythmic breathing, fixed eyeballs, no spontaneous blinking, no corneal reflex in response to

Table 2
Glucose and cortisol from all measured animals.

Abattoir	Østfold (mobile)	Hordaland (mobile)	Akershus (stationary)
No. animals	59	32	63
Cortisol (ng/ml)	19.8 ± 9.1[a]	21.0 ± 12.5[a]	34.2 ± 16.9[b]
No. animals	12	30	31
Glucose (mg/ml)	2.87 ± 0.27[ab]	3.17 ± 0.51[a]	2.72 ± 0.36[b]

[a,b]Different superscripts within line represent significant differences ($P < 0.01$) between slaughter groups.

movement or touch, open pupils that do not respond to light, and no reaction to painful stimuli (EFSA, 2004). At the stationary slaughterhouse, using electric stunning, the stun quality was evaluated according to EFSA (2004) criteria; grand mal epileptoid seizure with collapse and a tonic phase while the tong is held on head, before going into a clonic phase, no rhythmic breathing; the eyeballs may roll up, but there should be no eye reflexes and no reactions to painful stimuli. For both methods of stunning, when the animal was hanging on the rail, its head should hang straight down and the back should be straight without showing an arched back righting reflex. Due to the short stick to stun interval at the stationary abattoir, testing of reflexes had to be done after sticking and shackling. At both abattoirs the animals were observed during bleeding.

2.5. Meat quality parameters

From each of three locations 12 carcasses were followed for later measurement of Warner–Bratzler (WB) shear force, pH and temperature development. The carcasses were classified according to the EUROP grading system for muscle conformation and subcutaneous fatness. All carcasses were hung from the Achilles heel after slaughter, but there were differences in cooling rates and time of muscle excision between the locations. At the stationary abattoir (Akershus) the carcasses were chilled at 10 °C for 4 h after slaughter, then moved to a 4 °C storage chamber until 2 days post mortem. The *M. longissimus dorsi* (LD) was excised and packed in vacuum bags before further ageing at 4 °C until 7 days post mortem. The carcasses from the mobile abattoir in Østfold and Hordaland were chilled at, respectively, 13 and 10 °C for 24 h post mortem. Then these carcasses were hung at 4 °C until 7 days post mortem, before the *M. longissimus dorsi* (LD) was excised and packed in vacuum bags. The muscle samples from all three locations were frozen at −20 °C 7 days post mortem. The temperature of the carcasses was monitored at 10 min intervals during chilling using loggers (Kooltrak, Model 214002, Geisenheim, Germany) attached to the surface of the round. Muscle pH was measured 7 days post mortem, before the samples were frozen, by inserting a glass-stick probe (InLab®Solids, Mettler Toledo Intl. Inc., Greifensee, Switzerland), connected to a pH meter (Portamess 752 Calimatic, Knick, Berlin, Germany) into the muscle. The muscles were frozen for 2–4 weeks before thawing overnight, then cut into 3.5 cm thick slices, vacuum-packed in plastic bags and cooked in water bath at 70.5 °C for 50 min before cooling in ice water for 50 min. After reheating to room temperature the meat slices were cut into rectangular pieces of 1 × 1 × 3 cm along the fibre direction. Warner–Bratzler shear force was measured on 10 parallels from each muscle sample with a V-shaped blade attached to an Instron Materials Testing Machine (Model 4202, Instron Engineering Corporation, High Wycombe, UK). Crosshead speed was 100 mm/min, and the average maximum force (given as N/cm^2) for the parallels was used in the data analysis.

2.6. Statistical analysis

The statistical analyses were performed with JMP Pro, version 9.0 (SAS Institute, 2006). Assumptions of normality were examined with a Goodness of Fit test. None of the parameters were found to be normally distributed. A Wilcoxon test with a Chi-Square approximation was applied to test for effects of slaughter method on stress indicators and meat quality characteristics. Relationships between variables were tested for by applying Pearson correlations. Mean values are given with standard errors (SE) unless stated otherwise. Probability values of $P \leq 0.05$ were considered significant and values ≤ 0.1 as indicating a tendency.

3. Results

3.1. Stunning and sticking

At the mobile abattoir, using captive bolt, the stun to stick interval was on average 24.3 ± 0.5 s for lambs without horns and on average 14.7 ± 2.08 s for the 8 horned animals. At the conventional slaughterhouse the animals were bled in average 8.9 s after being electrically stunned. In general the quality of anaesthesia was good, both at the mobile abattoir and the conventional slaughterhouse. However, there were a few incidents at the conventional slaughterhouse where animals showed transient rhythmic breathing and eye reflexes, which may indicate inadequate stunning quality.

3.2. Physiological parameters

Levels of serum cortisol were significantly lower ($P < 0.001$) in lambs slaughtered at the mobile abattoir compared to the lambs slaughtered at the stationary slaughterhouse when all 154 samples were considered. There was no difference in cortisol level between the two locations operated by the mobile abattoir, Table 2. It was further found that the lambs slaughtered at the stationary slaughterhouse (Akershus) had significantly lower ($P < 0.001$) glucose levels than the lambs slaughtered at the mobile abattoir in Hordaland. The samples obtained

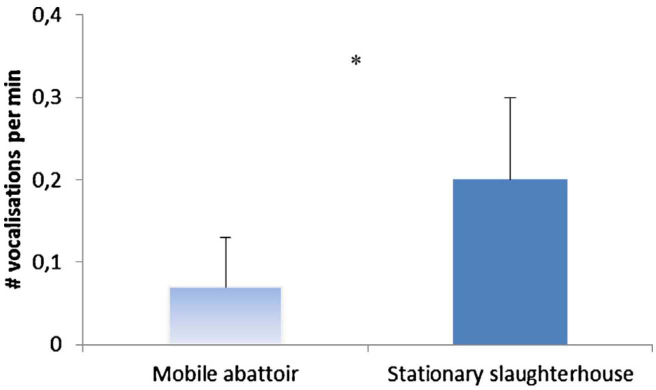

Fig. 1. The frequency of vocalizations in Norwegian lambs according to slaughter method. *($P < 0.01$).

from the mobile abattoir in Østfold had glucose content in between the two other locations and was not statistically different from them.

3.3. Behavioural parameters

Lambs slaughtered at the stationary slaughterhouse vocalized significantly more than lambs slaughtered at the mobile abattoir ($P < 0.01$; Fig. 1). Also, the lambs at the stationary slaughterhouse showed significantly higher frequency of aggressive behaviours compared to the lambs at the mobile abattoir ($P < 0.01$; Fig. 2). No significant effect of slaughter method was found for any of the other behavioural parameters.

3.4. Temperature during ageing

Average temperature curves for each location, measured on the surface of the hind leg of the carcasses, are shown in Fig. 3. Although the temperature inside the centre of the LD muscles was supposed to decrease slightly slower than at the surface of the legs, these curves clearly show differences in muscle temperature between the locations. The carcasses from the stationary abattoir in Akershus had a much faster cooling rate than carcasses from the two mobile locations. However, all LD samples were aged at approximately the same temperature (4 °C) from 30 h post mortem until freezing 7 days after slaughter.

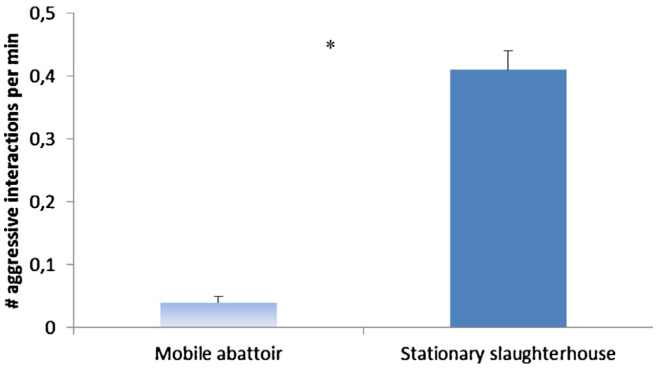

Fig. 2. The frequency of aggressive interactions (push, butt and mount) in Norwegian lambs according to slaughter method. *($P < 0.01$).

3.5. Muscle pH

Ultimate pH in the LD muscles from the lambs slaughtered at the Akershus abattoir (stationary) was significantly higher than the lambs from the two mobile abattoirs ($P < 0.001$), Table 3. In addition, the range of pH values was significantly ($P < 0.001$) wider for the Akershus abattoir compared with the other two locations.

3.6. Warner–Bratzler shear force (WB)

The muscle samples obtained from the Akershus abattoir (stationary) had significantly higher ($P < 0.05$) mean shear force value than the Østfold samples (Table 3), while the samples harvested from the Hordaland abattoir were in between.

3.7. Correlations between stress indicators and meat quality parameters

Serum cortisol level and WB was positively correlated ($r = 0.39$, $P < 0.05$). Additionally, a positive correlation between cortisol level and the incidence of aggressive interactions was demonstrated ($r = 0.47$, $P < 0.05$). The frequency of vocalizations and aggressive interactions was positively correlated ($r = 0.73$, $P < 0.01$). Furthermore, the frequency of aggressive interactions was also positively correlated to meat pH ($r = 0.66$, $P < 0.05$). Finally, the frequency of aggressive behaviours was negatively correlated to blood glucose levels ($r = -0.46$, $P = 0.05$).

4. Discussion

Animals for meat production are exposed to a variety of potential stressors prior to slaughter, including handling, unfamiliar environments, social disturbance and suboptimal design of the slaughterhouse (Warris, 2003; Terlouw, 2005). It is established that transport represents one of the major stressors in this context (Tarrant, 1990; Lambert et al., 1998). In the present study, the lambs slaughtered at the stationary slaughterhouse had higher concentrations of cortisol compared to the animals at the mobile abattoirs. At the stationary slaughterhouse, the animals were lairaged overnight; it is thus difficult to accurately assess the possible impact of the transport on cortisol concentration in the present study. Transport stress has been found to increase cortisol levels in domestic animals, including sheep (Odore et al., 2004; Ekiz et al., 2012). Although numerous experiments have examined the impacts of transport in animals, only a few of these have compared animals that are transported prior to slaughter to animals that are not. However, Liu et al. (2012) studied the effects of transport *per se* and lairage time on some blood indicators of welfare and meat quality traits in male sheep. Male sheep were randomly allotted to one of seven groups: one control group (untransported) and six lairage groups (8 h road transport with 0, 2, 6, 12, 24 and 48 h lairage times correspondingly). Sheep in 48 h group showed higher pH (24 h) than that in other groups. After transport, sheep in 0, 2, 24 and 48 h groups displayed higher cortisol and glucose concentrations than that in the control

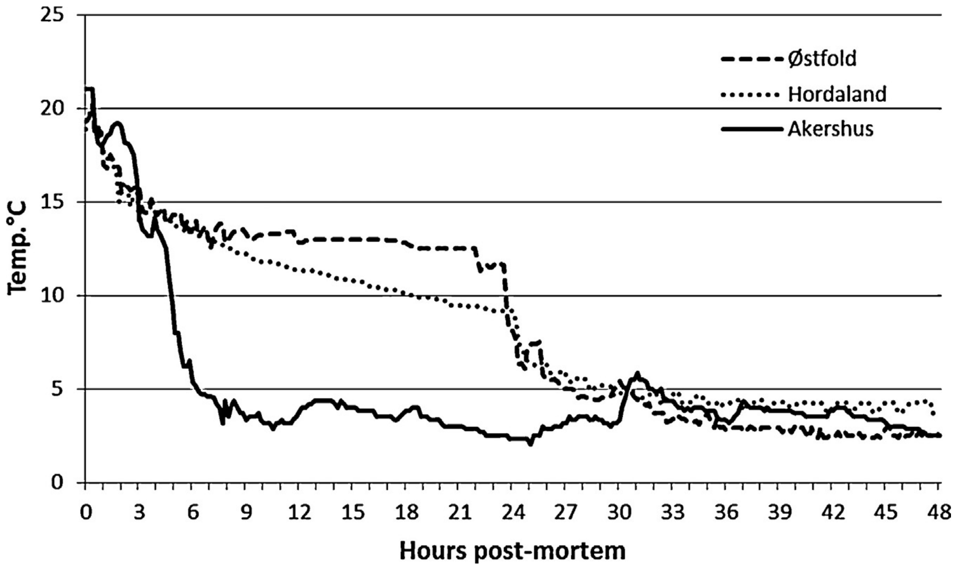

Fig. 3. Temperature profile of the carcasses during the first 48 h after slaughter from the three locations.

group. Pearson et al. (1977) recorded post-slaughter cortisol concentrations in lambs slaughtered either at a large conventional slaughterhouse or a small research abattoir. Lambs slaughtered at the small abattoir had lower cortisol levels compared to animals at the commercial slaughterhouse, and this was explained by reduced handling and a quiet environment at the small abattoir. These results correspond with the overall present findings. The cortisol levels in lambs from Østfold (mobile) and Akershus (stationary) did not differ significantly, still the highest concentrations of cortisol were found in lambs slaughtered at the stationary abattoir. It is found that serum levels of cortisol may be reduced during lairage at the slaughterhouse (Kim et al., 1993; Bornèz et al., 2009). Indeed, the lairage period may allow a recovery of the transportation stress preceding slaughter, but also involves a novel environment and often food deprivation, which may cause additional stress in animals (Fauciatano, 1998). Another known stress factor that differed between the stationary and the mobile plants was that lambs were fully sheared before slaughter at the stationary abattoir but only clipped a stripe along the ventral midline at the mobile abattoir. It is known that shearing may cause a significant change of the blood parameters involved in the stress response, including cortisol (Carcangiu et al., 2008). To improve sheep welfare, shearing is now performed after killing at most Norwegian slaughter plants. Indeed, the application of cortisol measures when estimating short term stress in sheep exposure may entail some weaknesses. According to the classic study by Kilgour and De Langen (1970), sheep is a species that have a uniform response-time of 30 to 40 min between exposure to stressful stimuli and maximum blood cortisol concentrations. The severity of the stress after peak output of cortisol can be estimated by the slope of the decline to basal level. Thus, it would be highly valuable to measure cortisol not just immediately as in this study, but after stress and over time, because a single or a late test could differ from the real response.

Moreover, increased level of blood glucose is often observed during acute stress in animals, and this relationship is mediated via catecholamines and glucocorticoids (Shaw and Tume, 1992). In sheep, it is found that blood glucose typically rises prior to slaughter (Shaw and Tume, 1992). Still the levels may decrease if the animals are stressed for a longer period (Paulsrud and Olsen, 2002). In the current study, the lambs slaughtered at one of the mobile abattoir locations had significantly higher levels of glucose than the animals at the stationary slaughterhouse. This may indicate that the lambs at the stationary abattoir had been exposed to stress for a longer period of time, thus depleting their glycogen reserves, whereas the lambs at the mobile abattoir remained relatively calm until

Table 3
Results for 36 lambs slaughtered at three different abattoirs.

Abattoir	Østfold (mobile)	Hordaland (mobile)	Akershus (stationary)
No. animals	12	12	12
Carcass weight (kg)	17.5 ± 1.3	18.4 ± 1.8	18.6 ± 1.5
EUROP[c]	7.92 ± 1.24[a]	9.33 ± 1.16[b]	8.75 ± 1.42[ab]
Fat grade[d]	5.92 ± 1.08	6.50 ± 0.80	6.25 ± 0.87
pH (7 days pm)	5.57 ± 0.03[a]	5.54 ± 0.03[a]	5.82 ± 0.31[b]
WB (N/cm^2)	19.2 ± 3.4[a]	23.7 ± 7.8[ab]	28.9 ± 9.0[b]
Cortisol (ng/ml)	23.5 ± 9.7[ab]	16.2 ± 7.9[a]	32.6 ± 15.8[b]
Glucose (mg/ml)	2.87 ± 0.27[ab]	3.01 ± 0.35[a]	2.70 ± 0.21[b]

[a–b]Different superscripts within line represent significant differences ($P < 0.05$) between slaughter groups. [c]EUROP muscle conformation where *E*+ = 15,. . .,*P*– = 1. [d]1 = very lean,. . .,15 = very fat.

minutes before they were slaughtered and could mobilise glucose. Normally, glucose levels reflect the nutritional status of animals, with food deprivation leading to reduced blood glucose (Shaw and Tume, 1992). A weakness of the current study is that there is no information regarding baseline levels of glucose, which in fact is rather important. Neither the lambs at the mobile abattoir nor the ones at the conventional slaughterhouse had access to food while they were kept in holding pens. Furthermore, glucose levels may also be affected by lipid and protein contents in the diet. In the present study, lambs originated from several farms, which may have contributed to the glucose differences observed between the three localities. It is important to underline that in the present study there are several undefined and uncontrolled variables which may have influenced the secretion of cortisol and glucose into the bloodstream. Moreover, it could be speculated that the increase in glucose observed in one of the mobile abattoirs may be attributed to a different mechanism than the action of cortisol, for instance due to catecholamines. It could be that cortisol was not responsible for triggering glucose, since blood samples were taken at the same time, and normally the increase of glucose in plasma is not as rapid as for cortisol. Measuring glucose just after an acute experiment may be considered a source of error, because there is the probability of not measuring any change. As with cortisol, it would be valuable to recognize basal or pre-stress (pre-slaughter) levels.

Behavioural alterations are often the first signs of distress in animals (Ayo et al., 2002). The behavioural responses of livestock to pre-slaughter procedures vary and are contingent upon the apparent stimuli. Several behavioural indicators were recorded in this study, but only a few showed significant differences between the two types of abattoirs. It was found that lambs at the stationary slaughterhouse had higher frequency of aggressive interactions than the animals from the mobile abattoirs. In addition, a difference in the rate of vocalisation between the slaughter facilities was found. Based on these parameters it was difficult to conclude that the impact of stress was unbalanced between the mobile and stationary abattoirs. However, the overall interpretation of behaviour was that the animals at the conventional slaughterhouse were more alert, restless and distressed than the lambs at the mobile abattoir, which also was supported by the glucose and cortisol results. Such behaviours may be induced by crowding and mixing of animal groups leading to social instability and formation of new ranking systems (Warris, 2003), or be due to other stressors, such as feed deprivation, novel environments or handling (Chrousos, 1998; Steckler, 2005; Miranda-de la Lama et al., 2010).

It is formerly shown that various pre-slaughter demands may enhance stress and induce behavioural alterations in sheep (Baldock and Sibly, 1990; Parrott et al., 1994). Further, a relationship between cortisol levels and aggression was observed, and also between vocalization and aggression, indicating emotional stress. A negative correlation between aggressive behaviours and glucose levels was found. One might speculate that the most aggressive animals during their actions had depleted their glycogen reserves, consequently reducing blood glucose. However, an alternative explanation could be that the individuals with the lowest glucose values were the most frustrated and thus, most aggressive (DeWall et al., 2011).

A correlation between cortisol levels, vocalization rates and tenderness was seen, thus supporting earlier findings that stress may be detrimental to meat quality (Terlouw, 2005; Ferguson and Warner, 2008; Adenkola and Ayo, 2010). However, as shown in Fig. 4 the correlation between cortisol and WB shear force was strongly dependent of the two samples which had cortisol levels above 50 ng/ml. If these samples were omitted from the data the correlation disappeared. In the complete set of 154 cortisol samples there were only 9 samples which had concentrations above 50 ng/ml, and the majority of these samples were collected at the stationary slaughterhouse. Unfortunately, corresponding WB values were not measured for these samples. Although found to be significant, some of the correlation coefficients values are rather low, explaining a relatively small part of the variability. This implies that caution should be used in making wide reaching conclusions regarding these relationships.

In the present study tenderness was assessed by the mechanical WB shear force method which correlates very well with sensory tenderness (Sivertsen et al., 2002). Meat samples which achieve WB values below 50 N are considered as very tender while samples with values above 80 N are categorized as tough. Since the single highest WB value found in the present study was 43.7 N all samples were classified as very tender. Still there were significant differences between the abattoir locations. The stationary plant in Akershus had highest mean WB value while the meat samples obtained from the mobile abattoir in Østfold had lowest WB value. Consequently it seems like mobile abattoirs give more tender meat than stationary plants. However, such a conclusion cannot be justified by the WB values alone. As previously mentioned several parameters interact to determine the final tenderness, and muscle temperature post mortem has enormous impact. The carcasses at the mobile abattoir were allowed to cool slowly to approximately 10 °C during the first 24 h after slaughter, while the carcasses from the stationary plant were chilled more rapidly to approximately 4 °C within 10 h (Fig. 3). The calpains are the most active proteolytic enzymes during the early post mortem period (Morton et al., 1999), and their activity increases with temperature (Pomponio and Ertbjerg, 2012). Therefore the difference in storage temperature during the first day after slaughter may have influenced significantly the WB shear force values.

Although stress is an unwanted burden for the animal it may give tender meat for the consumer, since stress prior to slaughter may result in meat with high ultimate pH (Warner et al., 2005). All meat samples from the mobile abattoirs in Østfold and Hordaland had low pH values, while 4 samples collected at the stationary plant had elevated pH. In agreement with the literature the two samples which had pH-values above 6.3 were found very tender (Fig. 5). Stunning method may affect stress responses and meat quality traits in animals (Vergara et al., 2005). In the present study, all lambs selected for meat quality testing were adequately and effectively stunned. The mobile abattoir applied penetrating bolt, whereas the stationary

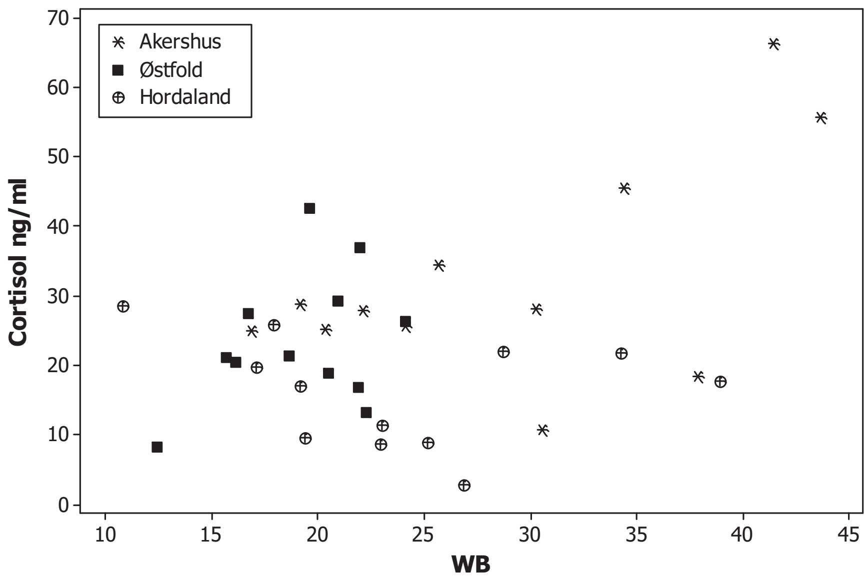

Fig. 4. Scatterplot of cortisol versus WB shear force from the 3 locations.

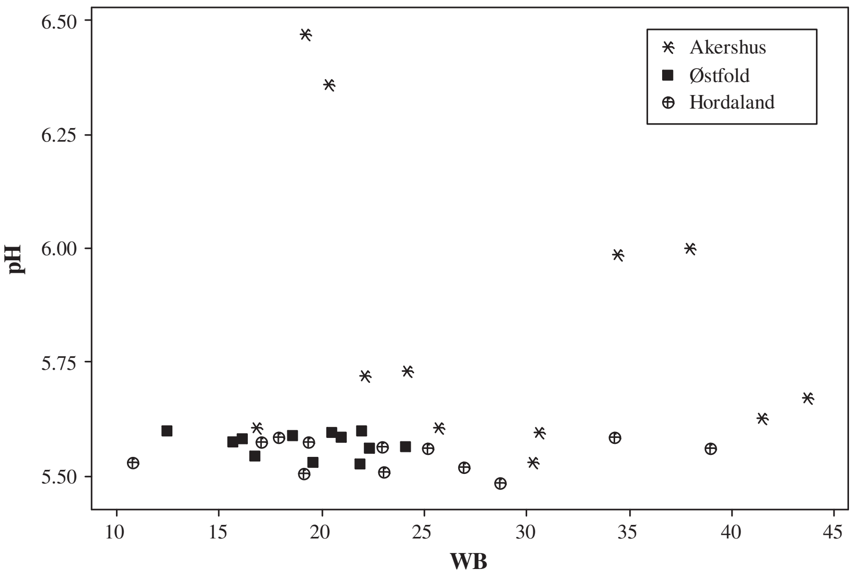

Fig. 5. Scatterplot showing pH versus WB shear force.

slaughterhouse used electrical stunning. Regarding cortisol and glucose, it remains questionable whether type of stunning method could have impinged on the levels, given the short time from stunning to bleeding and blood sampling (24.3 versus 8.9 s for the mobile and stationary abattoir, respectively). However, this possibility should not be ignored. With respect to ultimate pH and tenderness the differences observed in meat from mobile and stationary abattoir may partly be due to the differing stunning procedures, as stunning method is established to affect certain meat quality traits (Gregory, 1998; Vergara and Gallego, 2000; Anil et al., 2004).

5. Conclusions

The current results indicate that application of a mobile abattoir may involve less stress to the animals, thus improving animal welfare. Despite higher WB values at the stationary abattoir all meat samples were very tender. However, the enhanced pH found for some samples at the stationary plant may suggest that meat from mobile abattoirs has better quality. In future studies it would be recommendable to complement cortisol and glucose with other stress indicators to establish a more complete profile due to stressors. The current data derive from a pilot field study, involving relatively few animals, and due to different facilities at the three sites, the quality of the observations differ to some degree. In addition, procedures varied between locations and so did the possible causes of stress. Further, the animals originated from different farms and geographical regions. Accordingly, there were many factors that may have impinged on the results. Also the findings are not unequivocal, and it could be that the range of analyses accessible to researchers at this point of time was not sufficiently precise to allow definitive conclusions to be drawn. Hence, prospective studies are imperative to gain more knowledge of the pros and cons related to mobile abattoirs and to establish whether such systems are preferable in order to improve animal welfare and optimise meat quality. Anyhow, more insight into plausible stress factors and how these may be reduced will be valuable knowledge for all types of slaughter plants.

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