THE EFFECT DURING GROWTH OF MODERATE EXERCISE ON MUSCLE METABOLIC CHARACTERISTICS IN VIVO AND RELATION TO MEAT QUALITY AND SENSORY PROPERTIES.

B. Essén-Gustavsson[1], K. Lundström[2], G. Larsson[3], A. Lindholm[1], A-C Nordin[1], I. Hansson[2] and E. Tornberg[3]., [1]Department of Medicine and Surgery, [2]Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences, S-750 07 Uppsala, [3]Swedish Meat Research Institute, S-244 00 Kävlinge, Sweden.

SUMMARY

Ten pigs were trained 3-7 min on a treadmill for 12 weeks (T-group) and ten pigs were untrained and only kept in pens (UT-group). Before training (around 25 kg) and 1 week before slaughter (around 110 kg) biopsies were taken from *M.longissimus dorsi* (LD) and *M.biceps femoris* (BF). Glycogen content and enzyme activities were similar between groups at 25 kg. After 12 weeks, the activities of citrate synthase (CS) and 3-OH-acyl-CoA dehydrogenase (HAD) had decreased to half in LD of both groups. In BF, CS and HAD activities had increased in the T-group but not in the UT-group. Before slaughter the T-group had higher glycogen content, CS, HAD and hexokinase activities in BF and higher CS activities in LD compared with the UT-group. In BF, pH_{24} was higher in the UT-group and three pigs had high pH_{24} indicating DfD. NO PSE meat was observed. Negative correlations to pH_{24} were achieved for glycogen content and CS and HAD activities. Moderate physical activity during growth increased glycogen content and oxidative capacity of muscle pre-slaughter. This leads to higher possibility to achieve normal pH_{24} i.e. less frequency of DFD-meat. If only normal meat is taken into account a more tender meat was found in the T-group.

INTRODUCTION

When muscles convert to meat, metabolic and structural changes occur postmortem which influence its quality and sensory properties. Meat of poor quality is usually either pale, soft and exudative (PSE) or dark, firm and dry (DFD). The sensory properties of both PSE and DFD meat are usually less satisfactory than those of normal meat (Barton-Gade and Bejerholm 1985). The condition of PSE meat is said to be due to an excessive glycogenolysis with lactate formation whereas that of DFD meat is related to low glycogen levels (for ref. Tarrant 1987). The postmortem metabolism can also be influenced by muscle metabolic characteristics and response preslaughter which may differ among pigs due to factors like heredity, nutrition, exercise and stress.

Meat quality is negatively affected in stress-susceptible pigs which at exsanguination have a different muscle metabolic response with lower glycogen content and phosphagen stores and higher lactate concentrations compared to non-susceptible pigs (Lundström et al. 1985). It has also been shown that the glycogen content as well as the oxidative capacity may differ in vivo among breeds and that this may be related to especially the tenderness of meat (Essén-Gustavsson and Fjelkner-Modig 1985). One important factor that can alter the glycogen content and the oxidative capacity of the muscle is physical activity (Essén-Gustavsson and Lindholm 1983). It was thus of interest to study the relationship between meat quality and sensory properties of the meat and muscle metabolic characteristics of pigs

Table 1. Mean and standard deviation (SD) of enzyme activities (µmol/g/min) and glycogen content (µmol/g) in M. longissimus dorsi and M. biceps femoris from ten untrained pigs (UT-group) and ten trained pigs (T-group) at a mean weight of around 25 and 110 kg

		M. Biceps Femoris		M. Longissimus dorsi	
		UT-group	T-group	UT-group	T-group
Citrate synthase	25 kg	20	22[e]	12[f]	12[f]
		(3)	(4)	(2)	(2)
	110 kg	19	33[c]	5	7[a]
		(4)	(6)	(1)	(1)
3-OH-acyl-CoA-dehydrogenase	25 kg	16	19	12[f]	11[f]
		(5)	(6)	(3)	(3)
	110 kg	19	25[a]	4	4
		(5)	(7)	(1)	(1)
Lactate-dehydrogenase	25 kg	1534[f]	1504[f]	1927[d]	1994
		(100)	(183)	(193)	(159)
	110 kg	2323	2291	2110	2064
		(257)	(120)	(135)	(148)
Hexokinase	25 kg	2.5	2.6	0.9	1.1
		(1.1)	(1.0)	(0.4)	(0.6)
	110 kg	2.0	4.0[a]	0.8	0.7
		(1.6)	(1.6)	(0.5)	(0.7)
Glycogen	25 kg	339	388	393[d]	412
		(83)	(62)	(72)	(64)
	110 kg	333	424[b]	346	381
		(80)	(31)	(58)	(40)

a, b and c indicate significant difference between UT- and T-groups and d, e and f indicate significant difference between pigs at 25 kg and 110 kg.

a; d $p<0.05$
b; e $p<0.01$
c; f $p<0.001$

Table 2. Mean and standard deviation (SD) of pH, drip loss (%), MQM, juiciness, flavour and tenderness in M. longissimus dorsi and M. biceps femoris after slaughter from ten untrained pigs (UT-group) and ten trained pigs (T-group)

	M. Longissimus dorsi		M. Biceps Femoris	
	UT-group	T-group	UT-group	T-group
pH	5.56	5.51	5.85	5.55[b]
	(0.13)	(0.10)	(0.28)	(0.05)
MQM	30.1	31.2	46.2	62.7[b]
	(5.0)	(5.2)	(13.0)	(11.4)
Drip loss	4.6	4.5	-	-
	(2.2)	(2.4)	-	-
Juciness	5.2	5.2	4.2	3.7
	(0.5)	(0.4)	(0.8)	(0.8)
Flavour	5.9	5.9	5.4	5.6
	(0.3)	(0.3)	(0.3)	(0.3)
Tenderness	5.7	6.2	4.6	5.1
	(0.7)	(0.8)	(1.2)	(0.9)

b indicate significant difference between UT- and T-groups; $p<0.01$.

raised under similar conditions but differing in their physical activity level.

MATERIAL AND METHODS

Two litters of crossbred Swedish Landrace (25%) X Yorkshire (75%) pigs were used in this study. Each litter contained ten pigs which at a mean weight of around 25 kg were split into two groups and thus four pens (3x3 m) housed five pigs each. Half of the pigs from each litter were assigned to training (T-group; 5 gilts and 5 castrates) and the other half were untrained (UT-group; 6 gilts and 4 castrates). The pigs in the T-group were moderately exercised on a horizontal treadmill (STO-Treadmill) for 3-7 min, 5 days/week during 12 weeks. The speed was during the first two weeks between 1-1.5 m/sec and was then slowly increased to 2-2.5 m/sec. The total distance covered during the training period was 33 500 meter. The Pigs in the UT-group were all the time kept in their pens. All pigs were fed a similar diet twice a day according to a restricted feeding scale based on the average weight of the pigs in the pen. At a mean weight of around 25 kg when the pigs were split into groups, muscle samples were obtained from both the *M.longissimus dorsi* (LD) and *M.biceps femoris* (BF) of all pigs. The pigs were anaesthetized and surgical samples were obtained which were about 5 x 5 mm large. After the training period and one week before the pigs were going to be slaughtered (mean weight around 110 kg) muscle samples were again obtained after the pigs had been anaesthetized. Needle biopsies were this time obtained from BF due to the growth of the muscle but surgical samples were obtained from LD. The muscle samples were immediately frozen in liquid nitrogen and stored at -80°C until analyzed.

Biochemical analyses:

The muscle samples were freeze-dried overnight and dissected free of connective tissue, blood and fat. As pure muscle as possible was then weighed (1-2 mg) and homogenized with an ultrasound disintegrator in 0.1 M potassium buffer (pH 7.3). The activities of citrate synthase (CS) as marker for citric acid cycle, 3-hydroxy-acyl CoA dehydrogenase (HAD) as marker for lipid oxidation, lactate dehydrogenase (LDH) as marker for lactate production and hexokinase (Hk) as marker for glucose phosphorylation were analysed at 25°C with fluorimetric techniques (Essén et al. 1980; Essén-Gustavsson et al. 1984). Another part of the dissected muscle (1-2 mg) was taken for glycogen analyses. The muscle sample was then put into a tube containing 1 ml of 1 M HCl and heated to 100°C for 2 h. Glycogen was analysed as glucose residues (Lowry and Passonneau 1973).

Meat quality analyses:

Muscle samples from BF and LD were obtained after slaughter. The pH value was measured about 24 hours after slaughtering- Internal reflectance (MQM) was analysed with the MQM-instrument (Meat Quality Marbling; Danish Meat Research Institute, Koskilde, DK), utilizing a wavelength near the infrared region, i.e. 940 nm. Drip loss was determined as the percentage loss of a 2.5 cm slice of LD hung in a plastic bag for four days in 2°C.

Sensory analyses:

Four days post mortem the LD samples (7th thoracic vertebra - 15th thoracic vertebra and without bone and lard) and BF samples were vacuum packed in plastic bags, frozen and stored at -20°C for one month. The samples were thawed over night in a chilling room at +4°C and were conditioned at room temperature (+20°C) for one hour. The samples of LD were cut into slices of 1.5 cm thickness. The slices were fried at 180°C on a griddle, with little margarine, immediately prior to the sensory evaluation. The frying was discontinued at a centre temperature of 68°C. The samples of BF were roasted whole in a roasting bag in an oven. The oven temperature was 175°C and roasting was discontinued at a centre temperature of 75°C. The BF was cut into 0.5 cm slices, which were divided and reheated in a microwave oven before serving. The sensory evaluation was carried out by a trained expert panel which consisted of 10 men and women. At each session the panelists were served 10 samples and with gilts and castrates at separate sessions. The following attributes were included in the test profile; meat flavour (1: very weak, 9: very strong); juiciness (1: none, 9: very large); tenderness (1: very tough, 9: very tender).

RESULTS

Enzyme activities and glycogen content from BF and LD are shown in table 1. No differences were seen in enzyme activities or glycogen content between groups at 25 kg in either of the muscles. In BF at 110 kg both CS, HAD and HK activities and glycogen content were significantly higher (1.3 - 2 x) in the T-group as compared to the UT-group. In LD only the CS activity was higher (1.3x) in the T-group than in the LT-group. When the pigs weighed around 110 kg the LDH activity had increased in BF of both groups (1.5x) whereas CS activity increased only in the T-group (1.5x) when compared to 25 kg. In LD of both groups, CS and HAD activities were decreased (0.3-0.6x) and in the UT-group LDH activity was increased (1.1x) and glycogen content decreased (0.9x). Meat quality and sensory parameters from muscle samples after slaughter are shown in table 2. The pH value did not differ in LD but was higher in BF of the UT-group (pH 5.85) as compared to the T-group (pH 5.55). Three pigs in the UT-group had high pH values ($pH \geq 6.0$) indicating DFD. In agreement with the high PH values for these pigs showing DFD, they also had the lowest values for MQM. Drip loss was similar between groups. The sensory parameters did not differ among groups. Excluding the pigs showing DFD in the UT-group and only comparing pigs showing normal meat quality tenderness was significantly higher in the T-group (mean 5.1) as compared to the UT-group (mean 4.0; $p < .05$). In BF negative correlations to pH were achieved for glycogen ($r = -0.6$) HAD ($r = -0.5$) and MQM ($r = -0.7$). The glycogen content was also positively correlated to CS ($r = 0.7$). When comparing the two litters significant differences were also seen for drip loss ($p < .05$), glycogen content ($p < .01$),tenderness ($p < .05$) and MQM ($p < .01$) in LD.

DISCUSSION

For several animal species, it is a common finding that those which are more physical active have a higher oxidative capacity in their muscles than those which are less active (Essén-Gustavsson 1986). The results of this study also show that oxidative capacity and glycogen content is higher in BF of pigs that have been moderately exercised for 12 weeks as compared to pigs that only were kept in their pens during the same period. The same pattern has previously been observed in M. gluteus of pigs that have been trained (Essén-Gustavsson and Lindholm 1983) and when comparing wild pigs with Landrace pigs (Essén-Gustavsson and Lindholm 1984). That only minor changes are observed in LD of training studies of pigs is probably related to the fact that LD is not such an active muscle as BF or gluteus when pigs exercise on a treadmill. In this study it was also interesting to note that the oxidative capacity had decreased in LD of both groups of pigs during the growth period from 25 to 110 kg. One explanation for this may be that oxidative capacity mainly is.located in type I fibres which have much smaller fibre areas than the non-oxidative type II fibres and that LD usually consists of less than 10% type I fibres (Essén-Gustavsson and Lindholm 1984). Due to growth, and in agreement with earlier studies muscle samples taken a week before slaughter therefore consist of a greater relative area of the non- oxidative type II fibres as compared to the samples taken at 25 kg (Cooper et al. 1970; Kiessling et al. 1982). This could then explain the decrease seen in oxidative capacity with growth. The marked increase seen in LDH in BF of both the UT-group and T-group may also be related to growth. It can not be excluded that some of the differences seen in enzyme activities when comparing data from 25 and 110 kg may be due to different sample sites due to marked growth of the muscle. Muscle samples were, however, taken from the same depth and area from both groups of pigs at each sampling occasion. The different results between groups therefore indicate that this is due to the physical activity level of the pigs.

An increase in both oxidative capacity and glycogen content is usually seen in training studies of both pigs (Essén-Gustavsson and Lindholm 1983), rats and humans (for ref. Saltin and Gollnick 1983). That the oxidative capacity and glycogen content of the muscles may influence the post-mortem metabolism was indicated in this study. Correlations were found between the CS and HAD activities and glycogen content and the pH values obtained from the same muscle groups 24 hours after slaughter. A high value for pH_{24} is usually related to DFD-meat. An abnormal rapid pH fall while the carcass temperature is still high, results in PSE-meat (for ref. Tarrant 1987). No PSE-meat was observed in this study but three of the pigs in the UT-group had high pH_{24} indicating DFD. These data therefore indicate that development of DFD may be prevented if muscles have a high glycogen content and a high oxidative capacity pre-slaughter. No marked changes were seen between groups when considering the sensory properties. It was however of interest to note when comparing only normal meat and thus excluding the three pigs which had indication of DFD meat that tenderness was higher in the T-group than the UT-group. Even if all pigs were kept in similar pens and were given the same diet one difference was that they consisted of pigs from two different litters. The data therefore also indicate that heredity is an

important factor to consider as the glycogen content pre-slaughter and drip loss and MQM after slaughter differed in LD when litters were compared. There was also a significant difference seen in the tenderness of meat between litters.

In conclusion, this study shows that moderate physical activity during growth increased glycogen and oxidative capacity of muscles pre-slaughter. This leads to higher possibility to achieve normal pH_{24} and therefore less frequency of DFD-meat. Furthermore, when comparing normal meat without DFD the T-group had a more tender meat as compared to the UT-group.

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REFERENCES

Barton-Garde, P.A. and Bejerholm, C. (1985). *Pig Farming* **33(12)**:56.

Cooper, C.C., Cassens, R.G., Kastenschmidt, L.L. and Briskey, E.J. (1970). *Developmental Biology*, **23**:169.

Essén, B., Lindholm, A. and Thornton, J. (1980). *Equine Veterinary Journal*, **12**:175.

Essén-Gustavsson, B. and Lindholm, A. (1983). Proceedings of the Fifth International Conference on Production Disease in Farm Animals, Uppsala, p. 356.

Essén-Gustavsson, R., Karlström, K. and Lindholm, A. (1984). *Equine Veterinary Journal*, **16(3)**:197.

Essén-Gustavsson, B. and Lindholm, A. (1984). *Comparative Biochemistry and Physiology*, **78A**:67.

Essén-Gustavsson, B. and Fjelkner-Modig, S. (1985). *Meat Science*, **(13)**:33.

Essén-Gustavsson, B. (1986). *In* Biochemistry of Exercise VI. Ed. B. Saltin. p. 435.

Kiessling, K-H, Lundström, K., Petersson, H. and Stalhammar, H. (1982). *Swedish J. Agric. Res.* **12**:69.

Lowry and Passonneau (1973). A flexible system of Enzymatic Analysis. Academic Press, New york.

Lundström, K., Rundgren, M., Edfors-Lilja, I., Essén-Gustavsson, B., Nyberg, L. and Gahne, B. (1985). 36th E.A.A.P. Meeting, Kallthea, Greece, Paper MP5.18.

Saltin, B. and Gollnick, P.D. (1983). *In* Handbook of Physiology, Skeletal Muscle. Bethesda: American Physiological Society. p.555.

Tarrant, P.V. (1987). *In* Proc. 33rd International Congress of Meat Science and Technology, Helsinki. p. 1.