

Heart size and mean muscle fibre cross-sectional area related to birth weight in pigs

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One of the aims in domestic pig breeding has been to increase the size of litters resulting in variation in birth weight of piglets. Pig breeding has also resulted in increased body muscle mass. Muscles with the same size can consist either of large number of thin muscle fibres or small number of thick muscle fibres. Larger body muscle content means that in living animal the heart must pump blood to larger muscle mass than earlier. Our interest in this study was to investigate the relationship between the pig's birth weight and (i) growth performance and carcass composition, (ii) the size of organs, and (iii) the mean muscle fibre cross-sectional area at slaughter. The study consisted of twenty pigs slaughtered at the age of 165±2 days. The day after the slaughter, the carcass composition was determined by dissecting the chilled carcass into lean, fat, bones, and skin and organs were weighed. The average cross sectional area of muscle fibres was determined from three fast-twitch muscles *longissimus dorsi*, *semimembranosus*, *gluteus superficialis*, and two slow-twitch muscles *infraspinatus* and *masseter*. The birth weight of pigs ranged from 0.9 to 2.2 kg. We found no clear relationships between the birth weight and the pig's growth performance from birth to slaughter. When the birth weight increased the heart weight at slaughter increased as well ($P < 0.01$). The heart weight was higher in those pigs with high carcass weight ($P < 0.05$) and with the high weight of total muscle mass in the carcass ($P < 0.001$). The cross sectional area of muscle fibres in *M. longissimus dorsi* ($P < 0.05$), *M. semimembranosus* ($P < 0.10$), and *M. gluteus superficialis* ($P < 0.05$) was larger in those pigs with low birth weight compared to those found in pigs with high birth weight.

Key-words: Pig, birth weight, heart, fast-twitch muscle, slow-twitch muscle, muscle fibre

Introduction

The birth weight of a domestic pig is about 1.5 kg, but can range enormously from about 0.5 kg to about 2.5 kg. The variation in the birth weight is large both within and between different litters, and low-birth-weight piglets are generally born in large litters and in litters of primiparous and old (> 5th parity) sows (Milligan et al. 2002). Low birth weight is associated with reduced piglet survival and postnatal growth rate (Dwyer et al. 1993, Milligan et al. 2002), but can also influence carcass composition and muscle characteristics at slaughter (Powell and Aberle 1980, Kühn et al. 2002, Gondret et al. 2005 and 2006).

As the pig grows, the weight of its organs increases, but their relative weight as a percentage of body weight declines. At birth, the relative weight of the heart is about one percent of body weight (Pond and Houpt 1978, p. 116), and declines gradually to 0.25–0.3% when the pig has reached a body weight of 90–105 kg (Priebes and Preetz 1977, Pond and Houpt 1978, p. 116, Yang and Lin 1997). Larger body muscle content means that in living animal the heart must pump blood to larger muscle mass than earlier. In a newborn pig, the relative weights of the liver and the kidneys are 3.1% and 1.0%, respectively, and in an adult pig, 1.4–1.5% and 0.3%, respectively (Pond and Houpt 1978, p. 97).

The growth of muscles is of great interest in meat-producing animals because of the commercial importance of muscle mass. As the size of a muscle increases, both the cross-sectional area and the length of muscle fibres increase (Swatland 1976). At birth, the cross-sectional area of different muscle fibre types (I, IIA, and IIB) is about the same (Bader 1983), but at slaughter, the cross-sectional area of type IIB fibres is about twice as large as that of type I and type IIA fibres in the *longissimus dorsi* muscle (Ruusunen and Puolanne 2004). Although the number of capillaries/fibre increases by age, the capillary density decreases due to muscle fibre hypertrophy (Oksbjerg et al. 1994).

The number of muscle fibres is fixed at birth (Wigmore and Stickland 1983). Muscle growth and ultimate muscle mass are largely determined by the

number and the growth of individual muscle fibres. If the number of muscle fibres is low, the thickness of muscle fibres must grow more than when the number of muscle fibres is high in order to attain the same muscle mass at slaughter. Runt pigs have been reported to have a lower total number of muscle fibres already in the uterus than their heavier littermates (Wigmore and Stickland 1983, Handel and Stickland 1987, Kühn et al. 2002). Therefore, for pigs with about the same carcass leanness and live weight at slaughter, the cross-sectional area of muscle fibres should be larger in those pigs with low birth weight than in those with high birth weight.

The purpose of this study was to investigate the relationship between the pig's birth weight and (i) growth performance and carcass composition, (ii) the size of heart, liver, and kidneys, and (iii) the mean muscle fibre cross-sectional area at slaughter. This study was a part of a larger research project that studied the effect of growth rate on carcass characteristics, the size of organs, the oxidative and glycolytic properties of slow-twitch and fast-twitch muscles, muscle fibre properties, blood parameters, and meat quality.

Materials and methods

Animals

The pigs were raised at MTT Agrifood Research Finland in Hyvinkää. The study consisted of 20 pigs (10 gilts and 10 barrows) from different litters. During the suckling and post-weaning periods, the pigs were housed with their litter mates and received standard pelleted starter and weaner diets, respectively. From a body weight of about 24 kg, the pigs were housed individually in pens of 1.0 m × 2.5 m. They received a diet which consisted of 75.30% barley, 21.82% soybean meal, 0.24% L-lysine HCl, 0.04% L-threonine, 0.04% DL-methionine, 1.21% mineral and vitamin premix, 0.36% monocalcium phosphate, and 0.99% limestone. This diet was formulated to meet the nutrient requirements of growing

pigs from 25 kg to 55 kg body weight (MTT 2004). Feed was given according to a restricted weight-based feeding scale, and the daily allowance was increased weekly from 13 to 30 MJ NE.

Slaughtering, sampling, and muscle fibre analysis

The pigs were slaughtered at the average age of 165 ± 2 d at the experimental abattoir of the University of Helsinki, Department of Food Technology. Muscle samples for analysing the mean fibre cross-sectional area were collected from *M. longissimus dorsi*, *M. semimembranosus*, *M. gluteus superficialis*, *M. infraspinatus*, and *M. masseter* from 20 to 40 minutes after the slaughter. The samples were frozen in liquid nitrogen and stored at -80°C until analysed. The cross-sectional area of muscle fibres were measured from sections stained using the myosin ATPase method (Brooke and Kaiser 1970) with an acid preincubation solution (pH 4.6). The sections (14 μm) were cut at -24°C in a cryostat (Reichert-Jung 2800 E, Germany). Stained sections were examined with an image analysis system using a computer programme (KS300, Carl Zeiss Vision GmbH, Germany). The mean muscle fibre cross-sectional area was calculated for different muscles by dividing the whole analysed muscle area by the number of fibres on that area. Always at least 400 muscle fibres were counted.

The day after the slaughter, the carcass composition was determined by dissecting the chilled carcass into lean, fat, bones, and skin, and the heart, liver, and kidneys were weighed.

Statistical analysis

Partial correlation coefficients were calculated to study the relationships of the birth weight and heart weight at slaughter to the pigs' growth performance, carcass composition, organ weight, and the mean cross-sectional area of muscle fibres in different muscles. The effect of sex was adjusted for. Re-

gression analysis was used when testing the effect of birth weight and weight of muscle mass in the carcass on the variation in heart weight. The data was analysed with the SAS programme (SAS® for Windows, Release 8.12).

Results

Growth performance, carcass composition and organ size

The birth weight of the pigs was 1.6 kg (range 0.9–2.2 kg) (Table 1). The birth weight of six pigs ranged from 0.9 to 1.3 kg, that of eight pigs from 1.4 to 1.7 kg, and that of six pigs from 1.8 to 2.2 kg. At the slaughter-age of 165 days, the pigs weighed

Table 1. Birth weight, live weight, and carcass weight of pigs as well as organ weights, carcass composition and mean muscle fibre cross-sectional area at slaughter (N = 20 pigs).

	Mean \pm s.d.
Birth weight, kg	1.6 \pm 0.3
Live weight at slaughter, kg	107.6 \pm 6.8
Weight gain, g d ⁻¹	
Suckling period	257 \pm 40
Post-weaning period	201 \pm 37
Fattening period	891 \pm 57
From birth to slaughter	642 \pm 40
Carcass weight, kg	85.5 \pm 5.5
Muscle mass, kg	51.0 \pm 2.7
Fat, kg	11.6 \pm 2.9
Heart, g	350 \pm 24
Liver, g	1621 \pm 188
Kidneys, g	368 \pm 42
Cross-sectional area of muscle fibres, x10 ³ μm^2	
<i>M. longissimus dorsi</i>	5.8 \pm 0.9
<i>M. semimembranosus</i>	5.9 \pm 0.7
<i>M. gluteus superficialis</i>	5.7 \pm 1.1
<i>M. infraspinatus</i>	5.2 \pm 0.8
<i>M. masseter</i>	2.7 \pm 0.5

107.6 kg (range 92.5–118.5 kg) and their carcass weight was 85.5 kg (range 70.8–92.5 kg). There were no significant correlations between the birth weight and the growth rate of pigs in any stages of growth from birth to slaughter. The lean meat and fat content of carcasses averaged $62.9 \pm 2.4\%$ and $14.2 \pm 3.0\%$, respectively, corresponding to a total muscle mass of about 51.0 ± 2.7 kg, and about 11.6 ± 2.9 kg of fat in the carcass. There was no significant relationship between the pigs' birth weight and carcass composition at slaughter.

The average weight of the hearts was 350 ± 24 g (range from 305 to 395 g), and its relative average weight was $0.33 \pm 0.02\%$ (range from 0.29 to 0.36%) of body weight. There was a positive correlation between the birth weight and the heart weight of pigs at slaughter ($r = 0.591$, $P < 0.01$), between the carcass weight and the heart weight ($r = 0.538$, $P < 0.05$), and between the weight of total muscle mass and the heart weight ($r = 0.778$, $P < 0.001$) (Table 2). The weight of total muscle

mass explained 61% of the variation in the heart weight, and the birth weight explained 36% of this variation. Including both the muscle mass and the birth weight in the regression model 75% of the variation in the heart weight was explained.

The average weight of the livers was 1621 ± 188 g (range from 1208 to 1939 g), and that of the kidneys 368 ± 42 g (range from 300 to 452 g), and their relative weights averaged $1.5 \pm 0.2\%$ and $0.34 \pm 0.04\%$ of total body weight, respectively. The weights of neither the liver nor kidneys significantly correlated with the birth weight.

Muscle fibres

The mean muscle fibre cross-sectional area was larger in the fast-twitch than in the slow-twitch muscles (Table 1). In the fast-twitch muscles, the largest mean muscle fibre cross-sectional area was

Table 2. Partial correlation coefficients between both the birth weight and heart weight at slaughter, and the weight gain, carcass composition, organ weight, and the cross-sectional area of muscle fibres.

	Birth weight	Heart weight
Body weight at slaughter	0.068	0.387
Carcass weight	0.234	0.538*
Weight gain		
Suckling period	0.377	0.074
Post-weaning period	-0.375	-0.115
Fattening period	-0.306	0.153
From birth to slaughter	0.006	0.365
Muscle mass	0.282	0.778***
Fat weight	-0.093	-0.020
Lean meat percentage	0.224	0.237
Fat percentage	-0.143	-0.164
Heart weight	0.591**	
Liver weight	-0.135	-0.135
Kidney weight	-0.127	0.402°
Cross-sectional area of muscle fibres		
<i>M. longissimus dorsi</i>	-0.483*	-0.283
<i>M. semimembranosus</i>	-0.397°	-0.509*
<i>M. gluteus superficialis</i>	-0.477*	-0.419°
<i>M. infraspinatus</i>	-0.061	0.265
<i>M. masseter</i>	0.111	0.047

Significance: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, ° $P < 0.10$

found in *M. semimebranosus*, followed by *M. longissimus dorsi* and *M. gluteus superficialis*. In the slow-twitch muscles, the cross-sectional area of muscle fibres was considerably larger in the *M. infraspinatus* than in the *M. masseter*. There was a negative correlation between the birth weight and the mean muscle fibre cross-sectional area in the fast-twitch muscles *longissimus dorsi* ($r = -0.483$, $P < 0.05$), *semimembranosus* ($r = -0.397$, $P < 0.10$) and *gluteus superficialis* ($r = -0.477$, $P < 0.05$) (Table 2). In slow-twitch muscles, however, we found no significant relationships between the birth weight and the mean cross-sectional area of muscle fibres. There was, however, a negative correlation between the mean cross-sectional area of muscle fibres in *M. longissimus dorsi* and the growth rate of pigs during the suckling period ($r = -0.667$, $P < 0.01$). The mean muscle fibre cross-sectional area showed no correlation with carcass composition.

Discussion

The birth weight of piglets varies considerably within the litter, and is related to the size of the litter. Low birth weight and high birth weight variation are the major contributors to poor pre-weaning survival and growth rate (Milligan et al. 2002). Several reports have indicated that low-birth-weight piglets gain weight more slowly, particularly during the suckling and post-weaning periods, and consequently reach similar slaughter weights at an older age than do piglets with a heavier birth weight (Nissen et al. 2004, Gondret et al. 2005 and 2006). In this study, however, we found no clear relationship between the birth weight and the growth rate of pigs in different stages of growth from birth to slaughter, nor did the birth weight correlate with the carcass composition. Similarly, Nissen et al. (2004) and Gondret et al. (2005) found no significant differences in carcass lean meat content at slaughter in relation to birth weight. However, some reports have shown that low-birth-weight piglets had more fat in their carcass at slaughter (Gondret et al. 2006) or as adults (Poore and Fowden 2004) than did the heavy-birth-weight

piglets.

The size of the heart in the domestic pig has increased with the selection for higher weight gain and leaner carcasses (Ciplef and McKay 1993, Yang and Lin 1997), but the heart size may not have been able to keep pace with the development of muscle growth (Yang and Lin 1997, Petrásí et al. 2003). In this study, the heart size averaged 350 g and constituted 0.33% of body weight. This is in accordance with earlier reports in which the relative heart weight of slaughtered pigs has ranged from 0.34% to 0.41% of body weight (Ciplef and McKay 1993, Yang and Lin 1997). We found a positive correlation between the birth weight and the heart weight at slaughter. A part of this did likely result from differences in body weight at slaughter, as the pigs were slaughtered at the same age and the heart weight correlated positively with the carcass weight ($r = 0.538$, $P < 0.05$) similarly as Oksbjerg et al. (2000) have also shown.

The function of the heart is to pump blood to the muscles, and the heart weight of slaughtered pigs has been shown to correlate with the protein content and protein gain in the carcass (Davey and Bereskin 1978). We also found a positive correlation between the heart weight and the weight of muscles at slaughter ($r = 0.778$, $P < 0.001$). Yang and Lin (1997) reported that the heart weight correlated negatively with backfat thickness. In the present study, the muscle weight at slaughter explained 61% of the variation in the heart weight. Our results seem to indicate that increased muscle growth puts pressure on the heart to pump more blood into the muscles, thus resulting in the enlargement of heart size. Poore et al. (2002) reported that small birth weight correlated negatively with blood pressure in the later life of the pigs, which could contribute to the development to cardiovascular diseases.

The heart rate increases very easily in pigs which weakens the function of the heart in stressful situations. Fattening pigs exercise little during their life in the piggery, and heart size seldom becomes a limiting factor. However, in transport to the slaughterhouse and during slaughter, the pigs are subjected to great stress. The strength of the heart and the oxidative capacity of muscles are important

in stressful situations to guarantee that the muscles receive enough oxygen. In very stressful situations, the limited heart capacity of lean pigs may result in the sudden death of the pigs (Petráši et al. 2003). Whether the size of the heart has grown in relation to body mass and to muscle mass under selection for leanness and fast growth of pigs remains unknown. One could, however, suppose that a large and strong heart will improve the stress resistance of the pigs.

As a pig grows, so does the size of the liver and the kidneys, but the size of the kidneys increases more than does that of the heart. In this study, neither the liver nor the kidney weight of slaughtered pigs correlated with the birth weight ($P > 0.05$). Several reports have shown that increasing dietary protein and amino acid supply or both increases the weight of both the liver and the kidney, but do not affect the size of the heart (Chen et al. 1999, Chiba et al. 2002, Szabó et al. 2001, Ruusunen et al. 2007). This is due to the role of the liver and the kidneys in protein metabolism. One has to consider that in the present study the feeding was restricted and the pigs were slaughtered at a constant age. The results may be different with ad lib feeding and in that case when the pigs are slaughtered at a constant live weight.

Breeding has resulted in leaner carcasses, although whether the carcass leanness has been achieved by a large number of thin muscle fibres or by a small number of thick muscle fibres remains unknown. In Denmark, Oksbjerg et al. (2000) studied changes occurred in the muscle fibre composition of Landrace pigs between the years 1976 and 1995. They found that the pigs of 1995 had higher daily weight gain and carcass lean percentage than did the pigs of 1976. However, the mean fibre cross-sectional area was smaller in the pigs of 1995, indicating a higher number of muscle fibres than in the pigs of 1976. In this study, low piglet birth weight led to a larger mean fibre cross-sectional area in fast-twitch muscles at the slaughter age of 165 days. Several other studies have also shown that piglet birth weight correlates negatively with muscle fibre thickness in *M. longissimus dorsi* (Bee 2004, Gondret et al. 2005), in *M. semitendinosus* (Hegarty and Allen 1978, Powell and Aberle 1981, Handel and Stickland 1987, Bee 2004, Gondret et

al. 2005), in *M. psoas major* and in *M. semimembranosus* (Powell and Aberle 1981, Hegarty and Allen 1978). In our study, the birth weight of pigs did not correlate with the muscle fibre cross-sectional area in slow-twitch muscles, whereas Handel and Stickland (1987) reported a larger muscle fibre cross-sectional area in the slow-twitch muscle *M. trapezius* in runt littermates. Gondret et al. (2005) found a similar phenomenon in slow-twitch muscle *M. rhomboideus*.

Hegarty and Allen (1978), Powell and Aberle (1981), and Kühn et al. (2002) reported from indirect measurements that smaller pigs have fewer muscle fibres at birth. Hegarty and Allen (1978) and Rehfeldt et al. (2000) pointed out that the postnatal hypertrophy of individual muscle fibres is higher when the muscle contains fewer muscle fibres in the muscle. These findings are in line with the negative correlations found between the birth weight and the cross-sectional area of muscle fibres in the fast-twitch muscles in this study. In contrast, in pigs selected at a fixed slaughter age, small littermates had smaller muscle fibres in *M. semitendinosus* compared to middle weight and heavy weight littermates (Nissen et al. 2004), i.e. the growth rate of fibres in small-birth weight may be slower than in larger birth-weight. Nissen et al. (2004) had taken the samples both in red and white part of *M. semitendinosus*. In the present study birth weight effected on muscle fibre cross sectional area in fast-twitch muscles but not in slow-twitch muscles.

Conclusions

The heart size of the pig at slaughter is related to its birth weight, carcass weight, and the amount of muscle mass in the carcass. Muscle fibres are thicker in *M. longissimus dorsi*, *M. semimembranosus*, *M. gluteus superficialis*, and *M. infraspinatus* than in *M. masseter*. In pigs with low birth weight, the cross-sectional area of muscle fibres in fast-twitch muscles at slaughter is larger than in pigs with high birth weight, when the pigs are slaughtered in the same age. In slow-twitch muscles this is not found.

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SELOSTUS

Sian syntymäpainon vaikutus sydämen kokoon ja lihassolujen paksuuteen teurasiässä

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Tutkimuksessa selvitettiin sikojen syntymäpainon yhteyttä niiden (i) kasvuun ja ruhon koostumukseen, (ii) elinten painoon ja (iii) lihassolujen paksuuteen teurasiässä. Tutkimus toteutettiin siten, että kaksikymmentä syntymäpainoltaan keskimäärin 1,6 kg:n painoista sikaa teurastettiin 165:n \pm 2 päivän ikäisinä. Sikojen elopaino oli teurastettaessa keskimäärin 107,6 kg ja ruhopaino 85,5 kg. Vuorokausi teurastuksen jälkeen jäähdytetyt ruhot leikattiin ja lihat, rasvat, sydän, maksa ja munuaiset punnittiin. Lihassolujen poikkipinta-ala mitattiin kolmesta vaaleasta ja kahdesta tummasta lihaksesta. Vaaleat lihakset olivat *longissimus dorsi*, *semimembranosus*

ja *gluteus superficialis* ja tummat lihakset *infraspinatus* ja *masseter*. Tutkimuksessa syntymäpainolla ei havaittu olevan selkeää yhteyttä sian kasvuun eikä ruhon koostumukseen. Mitä painavampi eläin oli syntyessään, sitä suurempi oli sen sydän teurasiässä. Lihasmassan kasvaessa myös sydämen koko kasvoi. Maksan ja munaisten painoon syntymäpaino ei vaikuttanut. Vaaleissa lihaksissa syntymäpainon ja lihassolujen keskimääräisen poikkipinta-alan välillä oli negatiivinen korrelaatio, eli samanikäisissä sioissa lihassolut olivat paksumpia syntymäpainoltaan pienemmillä kuin suuremmilla sioilla. Tummissa lihaksissa vastaavaa ei todettu.