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POSSIBLE RELATIONSHIPS OF SOME PARAMETERS OF REPRODUCTIVE SUCCESS IN SOWS TO SERUM CONCENTRATIONS OF THYROID HORMONES, INSULIN, IGF-I, CORTISOL AND PROGESTERONE

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In order to explore the possibility of predicting reproductive performance in sows and eventually altering the outcome, preprandial serum hormone concentrations and insulin-like growth factor-I (IGF-I) were determined in twenty crossbred females at mid and late gestation, several days after parturition and 1 day after weaning the litter. Mean triiodothyronine (T3) declined slightly from 1.31 to 1.12 nmol/1, while thyroxine (T4) decreased markedly during pregnancy from 55.2 to 34.8 nmol/l followed by recovery to 43.2 nmol/l. Basal insulin increased gradually but significantly from 3.0 to 6.9 mIU/l, while cortisol showed an increase during pregnancy (66 to 167 nmol/l) followed by a drop (110 nmol/l) and a second surge (148 nmol/l). Progesterone declined during pregnancy (41 to 26 nmol/l) and then dropped markedly post partum (1.1 nmol/1) in all except one sow. IGF-I increased more than four-fold after parturition (48 to 228 μg/l) and then decreased (132 μg/l).

The data obtained were analysed statistically in relation to measures of reproductive success such as litter size and weight, as well as changes in maternal body weight. It was found that midpregnancy preprandial insulin concentrations were correlated significantly with the subsequent numbers of farrowed (r = 0.530) and liveborn (r = -0.667) piglets. Moreover, one third of the variance (R^2 = 0.33) in weight of liveborn piglets was predicted by basal insulin negatively (P = 0.025) and progesterone positively (P = 0.044) obtained at midgestation. A multiregression including T4 (P = 0.027), cortisol (P = 0.05) and progresterone (P = 0.1) levels determined in late gestation described 45% of the variance associated with a measure of overall performance by the sows (net body weight gain + litter weight at weaning). Such an approach may help to elucidate the influence of changes in nutrition and management practice which affect reproductive success through changes in metabolic hormone concentrations.

Key words: metabolic hormones, IGF-I, sows, reproduction, interrelationships

INTRODUCTION

In polytocous species mean foetal size and the number of foetuses in a litter may be subjected to maternal constraint which is finally related to the nutrient supply. Namely, even with optimal maternal nutrition, genetic and environmental influences on the partitioning of nutrients between maternal and feto-placental tissues may affect the number and size of liveborn offspring. The metabolism of absorbed nutrients is subject to complex hormonal control and represents, at any one time, a balance of many interacting systems.

Insulin-like growth factor-I (IGF-I) has been implicated as having a role in foetal growth and maternal weight gain in mice and rats (Gargosky et al., 1991; Gluckman et al., 1992), whereas Klemcke and coworkers (1993) hypothesized that increased adrenal function, initiated prenatally, causes some instances of low birth weight in pigs. Although birth weight appeared to be the most significant factor in determining neonatal survival (Chavez and Forster, 1989), de Passille and coworkers (1993) provided evidence that elevated postpartum plasma progesterone may contribute to piglet losses by inhibiting lactogenesis. Moreover, litter size was positively correlated with prepartal progesterone and prolactin concentrations but negatively correlated with preprandial insulin.There is also an important interaction between size at birth and thyroid status which can be modulated by changes in maternal energy intake or iodine status (Symonds, 1995).

The partitioning of dietary and endogenous nutrients during lactation is not well understood even in man. Recently, it has been proposed that insulin and cortisol modulate the chanelling of nutrients between anabolic and anti-anabolic aspects of maternal body protein metabolism, whereas thyroid hormones and cortisol modulate nutrient partitioning towards milk production and visceral protein synthesis (Motil et al., 1994). In lactating sows Schams and coworkers (1994) concluded that the secretory patterns of metabolic hormones, especially the increase in IGF-I, may indicate regulatory mechanisms designed to reduce body protein mobilization.

In order to gain an overall impression of the involvement and interactions of the main hormonal systems in swine reproduction prior to more detailed studies, preprandial serum concentrations of the thyroid hormones, insulin progesterone and cortisol, as well as total IGF-I were determined in sows at midpregnancy, a few days prior to parturition, during lactation and one day after weaning the litter. The results obtained were related to parameters of reproductive success, such as litter size and weight as well as maternal body weight, and several significant associations found.

MATERIALS AND METHODS

Animals and management. Twenty crossbred cows (Swedish Landrace x Yorkshire) of parity ranging from 1 - 14 (mean 6.2) were mated naturally and kept in groups of six to seven animals until about 10 days before the expected day of parturition, when they were moved to individual boxes. Maize based diets containing 13.15 MJ metabolisable energy per kg air dry feed and 13.5% crude protein (N x 6.25) were offered at the rate of 2.6 kg per sow per day during gestation. The diets also contained wheat and sunflower oilmeal but differed slightly concerning the main protein supplement which consisted of soyabean oilmeal and/or raw peas. These differences appeared to have little influence on the parameters measured, except for preprandial insulin concentrations (Nikolić et al., 1995). After parturition the sows were offered, ad libitum, similar diets in which the protein level had been increased to 15.4% by the inclusion of fishmeal. The piglets were weaned at about 43 days after farrowing.

The body weights of the sows were determined at mating, before parturition and after weaning their litters. Liveborn offspring were weighed at birth and at weaning.

Procedure. Blood samples were obtained by jugular puncture in the morning (about 8^{00}) before feeding at about 50 and 9 days prior to as well as 11 and 44 days after parturition. The samples were allowed to clot and the serum separated by centrifugation. After storage at -20°C, the hormones triiodothyronine (T3), thyroxine (T4), cortisol, progesterone and insulin, together with total IGF-I, were determined as described earlier for pigs (Nikolić et al., 1994). All samples were determined at the same time. The mean intra-assay coefficients of variation of duplicate samples were as follows: T3 - 5.7%; T4 - 2.3%; insulin - 7.9%; IGF-I - 5.9%; cortisol - 6.5% and progesterone - 7.3%. Estradiol concentrations were determined in both post partal serum samples from four sows (CIS Serono).

Statistical analysis. The results were subjected to two-way analysis of variance (ANOVA) for the effects of time (sampling periods 1 - 4) and animal. The results for cortisol, thyroxine and IGF-I were complete (n = 80). One outlying result for T3 (>12 nmol/l) was excluded and a missing value calculated. Six outlying results for insulin (>40 mIU/l) were encountered. The remaining 74 results were analysed with missing values as above or by a nonortho ANOVA programme. Four outlying results for progesterone, two in the same sow, occurred in periods 3 and 4. They were included or excluded from the analysis as for insulin. Degrees of freedom for error were adjusted accordingly.

Simple correlations between the parameters examined were sought, as well as multiple regressions of dependent variables, such as litter size and mass, on hormone concentrations at each interval examined. Besides the numbers of piglets farrowed (mean 11.6, range 9 - 14), born alive (mean 10.4, range 8 - 13) and weaned (mean 8.7, range 3 - 12), their total weights and the body weights of the dams at mating (mean 191, range 127 - 243 kg), prepartum (mean 236, range 176 - 303 kg) and post weaning (mean 212, range 143 - 282 kg), parameters such as sow weight gain during pregnancy, overall net productive gain (litter weight at weaning + sow weight gain from mating to weaning) and net input during lactation (prepartal to weaning difference in sow weight subtracted from piglet weight at weaning) were included as dependent variables for multiregression on hormone concentrations. One primiparous sow lost seven out of ten liveborn piglets. Correlations were calculated with and without the results from this animal.

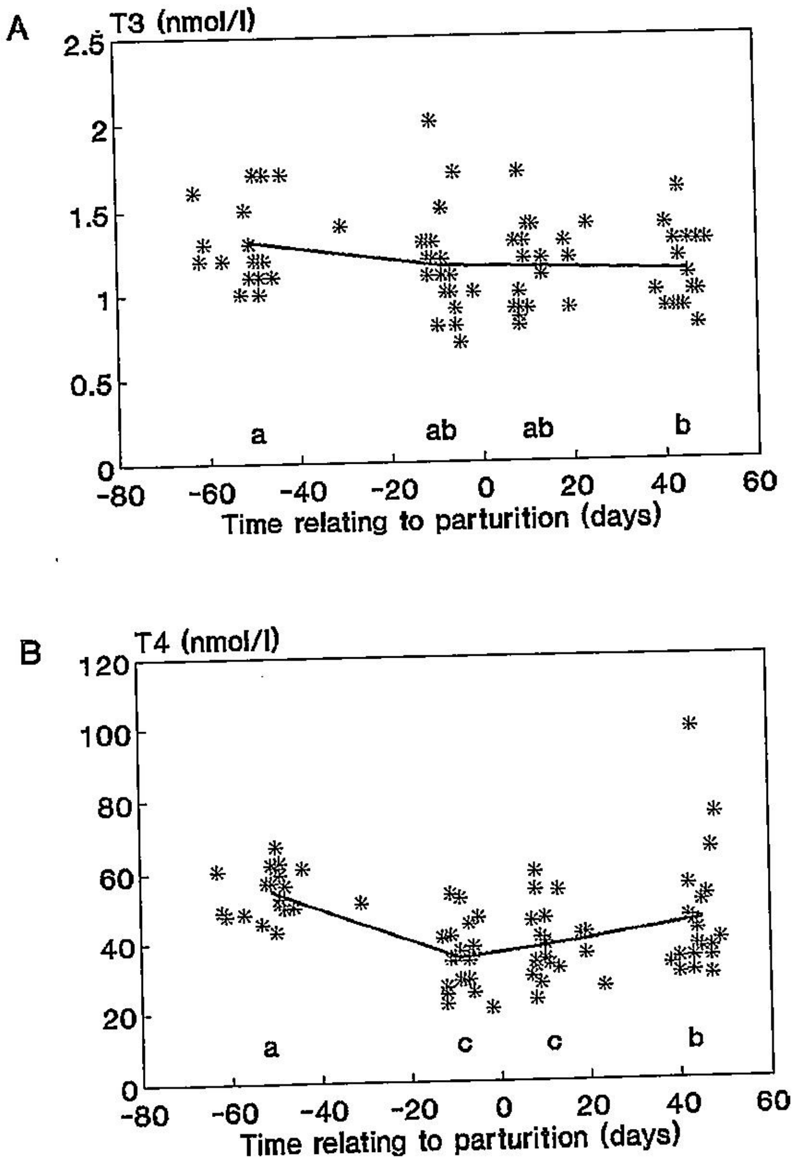

Figure 1. Individual and mean preprandial serum concentrations of T3 (A) and T4 (B) in twenty sows at four periods during the reproductive cycle. [abc]Means not denoted with the same subscript are significantly different ($P < 0.05$).

RESULTS

Triiodothyronine. The results obtained for serum T3 concentrations in twenty sows at time intervals during the reproductive cycle are shown in Figure

1A. Wide variations in individual values were encountered particularly a few days prepartum (range 0.7 - 2.0 nmol/l). Two factor ANOVA (n = 79) showed no significant animal effect (F = 0.84) but the effect of sampling period approached statistical significance (F = 2.08; P = 0.11). The difference between mean values for period 1 and period 4 and the regression of individual results on sampling day (r = 0.258; P = 0.021) were statistically significant (Figure 1A).

Concerning other hormones, T3 concentrations were postitively correlated with T4 and preprandial insulin levels (Table 1) in midgestation (period 1) but not at later periods individually. Nevertheless, the positive correlation between the thyroid hormones was statistically significant over the whole period examined. Concerning the success of the reproductive effort, the only statistically significant correlation to emerge was a negative relationship during lactation (period 3) with the number of liveborn piglets, which may reflect the demands of lactation. Namely, T3 is probably secreted in the milk, as in cows (Magdub et al., 1982), as well as being utilised in the work of milk synthesis and secretion.

Table 1. Statistically significant correlations between variables at each period and overall

Variables	Period	Number (n)	Correlation coeff. (r)	Probability (P)
T3 – T4	1	20	0.550	0.014
"	Whole	79	0.266	0.018
T3 – Ins	1	20	0.480	0.032
T3 – No liveborn	3	20	– 0.450	0.046
T4 – IGF-I	2	20	0.405	0.078
"	2	19	0.495	0.031
"	3	20	– 0.532	0.015
T4 – Overall gain	2	20	0.440	0.052
Ins – IGF-I	3	17	0.649	0.004
"	4	19	0.409	0.081
"	Whole	74	0.493	< 0.001
Ins – No farrowed	1	19	– 0.528	0.020
"	1	20	– 0.530	0.016
Ins – No liveborn	1	19	– 0.694	0.001
"	1	20	– 0.667	0.001
Cort – Sow wt. gain	1	20	0.438	0.050
"	2	20	0.477	0.033
Cort – Prog	4	20	0.461	0.040
Cort – No weaned	4	20	0.528	0.016
Prog – No weaned	4	20	– 0.488	0.028
Prog – Sow body wt.	4	20	0.448	0.047
Prog – IGF-I	4	17	0.632	0.006

Thyroxine. Serum concentrations of thyroxine were within the limits of normal values for swine found by other authors (Đurđević et al., 1992; Schams et al., 1994). The marked decrease from mid- to late gestation noted by the former was confirmed and was followed by a partial recovery during lactation (Figure 1B). Two factor ANOVA showed a very highly significant effect of sampling period (F = 19.3; p<0.001) and animal (F = 2.02; P = 0.022). Namely, some animals had consistently lower or higher T4 levels than others. The decrease in maternal T4 concentrations in late gestation may reflect the demands of the fetuses for iodide. However, increasing dietary iodide levels from 1 to 3 mg/kg did not prevent the prepartal drop in T4 (Đurđević et al., 1992). It appears that maternal T4 can pass through the placenta and contribute directly to the fetal pool (Morreale de Escobar et al., 1990), Spencer et al., 1989 which may be one reason for the change.

Besides T3, serum T4 concentrations tended to be positively correlated with IGF-I concentrations a few days before parturition (Table 1). If the sow which subsequently lost most of a live born litter was excluded this association was more close (r = 0.495; P = 0.031). Otherwise, serum T4 concentrations were not significantly correlated with any of the biochemical parameters measured at any period. There was a tendency for T4 concentrations during lactation (period 3) to be negatively correlated with litter weight at weaning (r = -0.415; P = 0.076; n = 19) which was reinforced if the forementioned animal which lost all except three of a litter of ten liveborn piglets was included (r = -0.532; P <0.01; n = 20). On the other hand, T4 concentrations a fewdays pre partum (period 2) tended to be positively correlated with total production (litter weight at weaning + weight gain of the sows from mating to weaning the litter; r = 0.405; P = 0.085; n = 19 and r = 0.440; P = 0.05; n = 20), which confirms the results of other authors for pigs and other mammals (Aumont et al., 1989; Berthon et al., 1993; Ruiz de Ona et al., 1991). mammals (Aumont et al., 1989; Berthon et al., 1993; Ruiz de Ona et al., 1991).

Insulin. Preprandial insulin concentrations showed the smallest differences between animals and the lowest mean value during midpregnancy (Figure 2A). Thereafter, values tended to increase, much more in some animals than others which confirms the findings of others (Armstrong et al., 1986; De Passille et al., 1993). Among the data six results (43 - 200 mIU/l) were above normal preprandial values (<30 mIU/l), two from period 2, three from period 3 and one from period 4, indicating either physiological changes associated with the nearby presence of the litter (Uvnäs-Moberg et al., 1984) or inadvertent access to feed before the samples were taken. Whether two factor ANOVA with six missing values or non-ortho ANOVA with corrected means was used, statistical analysis of the remaining results indicated significant effects of animal (F = 2.22 or 2.01; P <0.05) and sampling period (F = 4.53 or 4.34; P <0.05). The changes in preprandial insulin levels were consistent with the changes in nutritional environment of the sows (period 1 - group feeding with a limited amount of diet; period 2 - individual feeding with a limited amont of diet; period 3 - ad libitum feeding in individual boxes).

Apart from the forementioned positive correlation with T3 concentrations in mid gestation, insulin concentrations were positively correlated with total IGF-I concenrations during lactation and overall (Table 1). Most interestingly, midgestation preprandial serum insulin concentrations were negatively correlated with the total number of farrowed piglets ($r = -0.530$; $P = 0.016$) and more closely with the total number of liveborn piglets ($r = -0.667$; $P = 0.001$). Moreover, these data entered a statistically significant multiregression (Table 2) together with progesterone related to the total birthweight of the liveborn piglets ($R^2 = 0.332$; $P = 0.032$). De Passille and coworkers (1993) also found preparturient insulin concentrations to be negatively correlated with the number of piglets subsequently born. In our case this may have been a nutritional effect associated with the replacement of soyabean oilmeal and part of the maize with peas (Nikolić et al., 1995). This finding needs to be confirmed with a larger number of animals.

IGF-I. Total serum IGF-I concentrations were below 100 mg/l in each sow at both sampling periods during pregnancy (Figure 2B). There was a marked increase after parturition (greater than four-fold on average), which was highly variable between sows, followed by a decrease to values around 100 mg/l when the litter was weaned, except for four animals still exhibiting levels of 200mg/l and more. In general, our results confirmed those of other authors who found values of 40 - 50mg/l in cycling sows (Claus et al., 1992), 70 - 80mg/1 in midgestation (Lee et al., 1933) and late gestation (Farmer et al., 1994) and higher values in early lactation (Donovan et al., 1994; Schams et al., 1994). The fall from mid to late gestation observed by Lee et al. (1993) was not found here. Nevertheless, ANOVA showeda very marked effect of time ($F = 45.4$, $P < 0.001$) and also of animal ($F = 3.22$, $P<0.001$).

There were no significant direct correlations between IGF-I levels and any of the production parameters. However, prepartal IGF-I concentrations (period 2) formed and independent significant part, with cortisol, in a multiregression (Table 2) relating serum hormone concentrations to the gain in weight achieved by the sows between mating and parturition ($R^2 = 0.393$, $P = 0.014$, $n = 20$) and with thyroxine and progesterone, negatively in a multiregression relating net production during lactation (final litter weight minus loss in weight of the sow; $R^2 = 0.413$; $P = 0.033$, $n = 20$).

Cortisol. Serum cortisol concentrations showed a wide range at each interval examined (Figure 3A) but more especially after the stress of moving the sows to the individual boxes (period 2) and removal of the litter (period 4). Despite this scatter, statistically significant differences were found between the sampling periods ($F = 11.4$, $P < 0.001$) and animals ($F - 2.01$, $P = 0.02$). Costa and Varley (1995) found somewhat lower mean levels in early pregnancy but the data of Molokwu and Wagner (1973) obtained 7 days pre partum were exactly confirmed by our results.

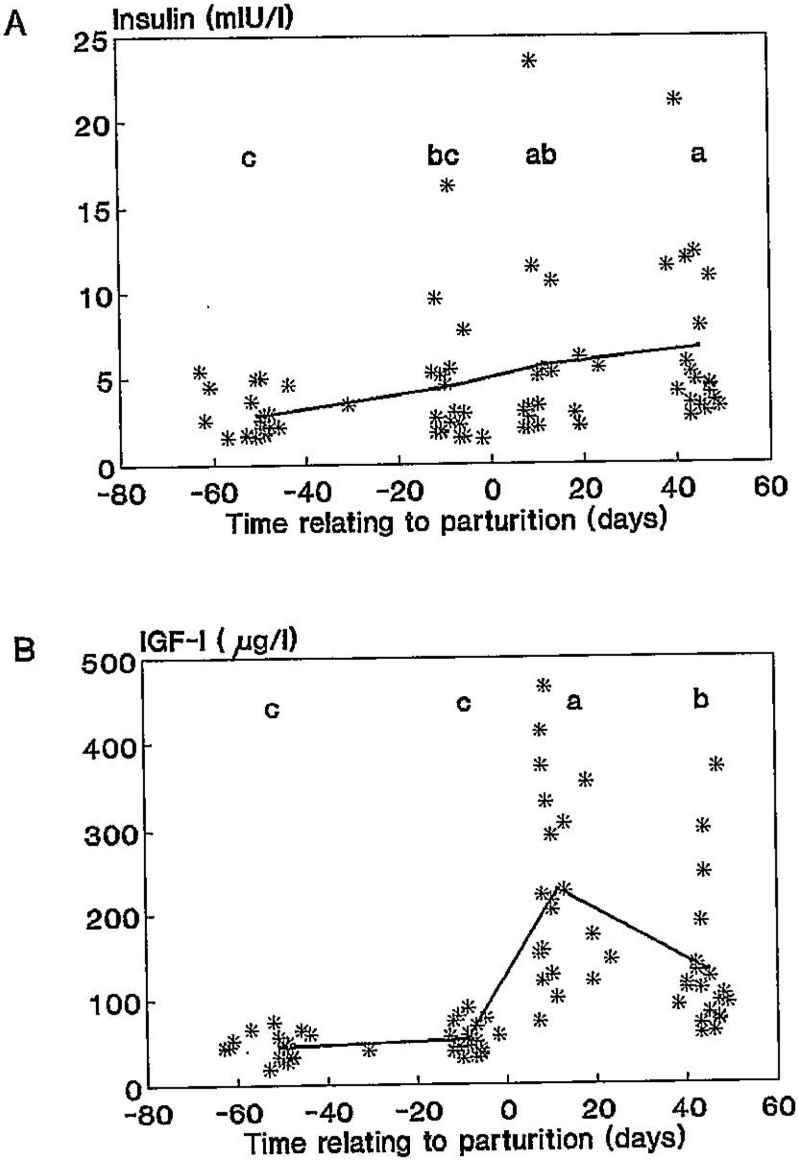

Figure 2. Individual and mean preprandial concentrations of insulin (A; n=74) and total IGF-I (B; n = 80) in twenty sows at four periods during the reproductive cycle. abc Means not denoted with the same supercript are significantly different ($P < 0.05$).

Table 2. Statistically significant multiple regressions relating hormone levels and criteria connected with reproductive performance

Variables		Period	Number (n)	Coefficient of deter. (R^2)	Probability (P)	
T3						0.078
T4	— Grain in preg.	Whole	76	0.153	0.007	0.069
Cort						0.003
Ins	— Liveborn wt.	1	20	0.332	0.032	0.029
Prog						0.044
Cort	— Gain in preg.	2	20	0.393	0.014	0.017
IGF						0.044
Cort						0.027
T4	— Total gain	2	20	0.446	0.021	0.050
Prog						0.109
T4						0.032
IGF	— Lactation prod.	2	20	0.413	0.033	0.038
Prog						0.105
T3						0.069
T4	— No weaned	4	20	0.703	0.001	0.001
Cort						0.004
IGF						0.006

Moreover, the cortisol level during pregnancy was positively correlated with gain in body weight of the sows ($r = 0.438$, $P = 0.05$, $n = 20$ in midpregnancy and $r = 0.477$, $P = 0.033$, $n = 20$ in late pregnancy). As mentioned above, the latter group of data entered a significant multiregression with IGF-I relating pregnancy gain in weight with biochemical parameters (Table 2). In addition, these prepartal serum cortisol data form part of a multiregression, together with thyroxine and progesterone, independently related to overall production (litter weight at weaning + weight gain of the sows over the reproductive cycle (mating to weaning) $R^2 = 0.446$, $P = 0.021$).

Serum cortisol levels at the final period were also related to progesterone concentrations, as discussed below, and were negatively correlated with the number of weaned piglets ($r = -0.528$, $P = 0.016$, $n = 20$). This correlation still approached statistical significance if all three sows with elevated progesterone levels were excluded ($r = -0.433$ $P = 0.081$, $n = 17$).

Progesterone. Progesterone concentrations showed a significant decline from very variable midpregnancy levels to more uniform values in late pregnancy, followed by a rapid fall to very low levels which were maintained in 17 of the 20 animals throughout lactation (Figure 3B). Two sows exhibited high values in the final blood sample after very low values in midlactation, probably indicating a lactational oestrus. Estradiol concentration was also determined in these samples. The values obtained were below 15 pg/ml similarly to a control sow, indicating that the five day cyclic elevation had probably passed. One animal, the heaviest, had a high value for progesterone at day 19 declinining somewhat (27

- 8.8 nmol/L) to day 42. Since there was a concurrent elevation of estradiol (88.7 decreasing to 15.6 pg/ml), this may reflect release of steroids from adipose tissue

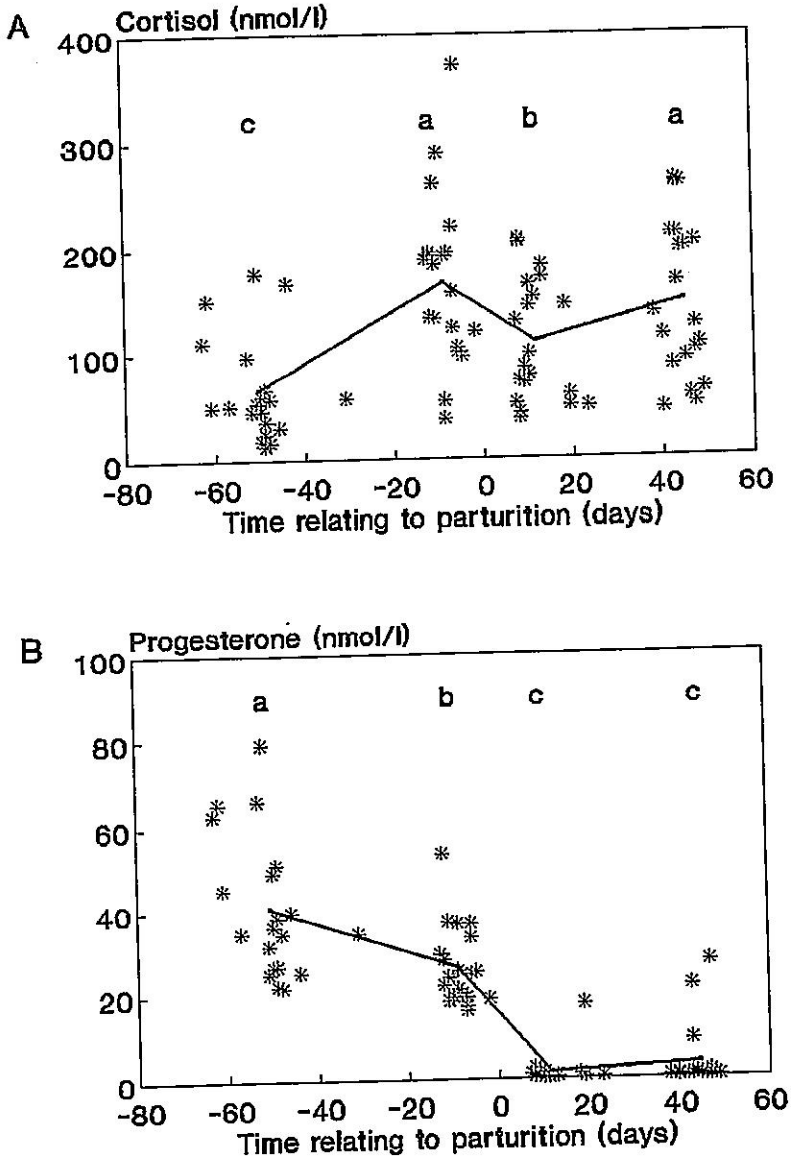

Figure 3. Individual and mean serum concentrations of cortisol (A) and progesterone (B) in twenty sows at four periods during the reproductive cycle. abc Means not denoted with the same supercript are significantly different ($P < 0.05$).

(De Passille et al., 1993). Correlations of progesterone levels with those of other hormones were made with and without these four outlying results.

Thus,two factor ANOVA (n = 76) indicated a highly significant effect of time (F = 79.1, P < 0.0001) but no effect of animal (F = 1.22, P =28), which was repeated for n= 80. For period 4, inclusion of the three high values gave a statistically significant correlation of progesterone with cortisol (r = 0.461, P = 0.040), no of piglets weaned (r = -0.488, P= 0.028) and final body weight of the sow (r = 0.448, P = 0.047), which all disappear when they are ignored. Namely, sows which suckled fewer piglets achieved higher body weights and probably entered oestrus earlier. A statistically significant positive correlation between progesterone and IGF-I emerged (r = 0.632; P = 0.006; n = 17) for the remaining sows.

DISCUSSION

When Gargosky and coworkers (1991) reversed the decline in serum IGF-I concentrations observed in late pregnancy in rats by subcutaneous infusion with IGF-I, they observed an increase in maternal weight which was not due to increased litter size, fetal or placental weight. Namely, IGF administration modified the mode of maternal nutrient partitioning in favour of the dam, in contrast to the situation in mice (Gluckman et al., 1992) where elevations in maternal IGF-I promoted fetal growth. The late pregnancy decline in IGF-I concentrations observed in sows (Lee et al., 1993) was accompanied by a decrease in the growth hormone dependent binding protein-3 (IGFBP-3) but these findings were not discussed in relation to requirements other than the need for mammary development. IGF-I concentrations during parturition could be decreased by previous immunisation against somatostatin (Farmer et al., 1994). In our study circulating IGF-I levels were maintaind from mid to late gestation, at which time they were correlated with T4 concentrations which had exhibited a decline during pregnancy. Moreover, the serum levels of both IGF-I and T4 together with progesterone independently predicted 41% of the variation in net input during lactation (piglet weight at weaning - prepartal to weaning sow weight loss). At the same time IGF-I and cortisol levels at this period combined to reflect 39% of the variance in sow weight gain during pregnancy. Namely, IGF-I levels appeared to be associated with overall anabolic processes affecting both dam and offspring together with the thyroid, adrenal and reproductive hormonal axes.

On the other hand, the main associations of preprandial insulin with the products of reproduction were observed at midgestation when differences between the animals were least. Since high preprandial insulin concentrations were negatively correlated with parameters relating to the number and weight in the subsequent litter, it appears that insulin is involved with nutrient partitioning favouring the dam at the expense of the fetuses. Thus, one third of the variation in weight of liveborn piglets was predicted by insulin (negatively) and progesterone (positively) levels in midgestation. Insulin was positively correlated with T3 levels at this time. Moreover, cortisol, thyroxine and progesterone levelsat this period together predicted 45% of the variance in total net anabolic input, while a significant proportion of the variance in number of weaned piglets was reflected by thyroid hormone, cortisol and IGF-I levels at weaning ($R^2 = 0.703$; $P = 0.001$; $n = 20$). However, exclusion of the sow which lost most of her litter and had a high serum T4 concentration led to a fall in the apparent influence of thyroid hormones leaving a statistically significant multiregression for cortisol and IGF-I only ($R^2 = 0.365$; $P = 0.026$; $n = 19$). The changes in cortisol concentration may be related to relocation and dyadic encounters as well as differences between animals associated with dominance status (Dalin et al., 1993; Fernandez et al. 1994). Our results post partum confirm the more detailed study of Schams and coworkers (1994). It is interesting that the late pregnancy positive correlation between IGF-I and T4 reversed to a negative correlation in early lactation. Maternal serum is the likely source of milk IGF (Donovan et al., 1994).

The only statistically significant associations between overall hormone levels were between T3 and T4 and between IGF-I and insulin, the former closest in midgestation and the latter during lactation when feeding was ad libitum. Insulin concentrations in cyclic sows also appeared to be determined by food intake which was in turn related to estradiol and progesterone concentrations (Claus et al., 1992).

These results were obtained with a relatively small number of animals exposed to usual farming practices and minimal blood sampling. Competition for feed in the first period coupled with genetic influences may have led to differences in hormone profiles which appeared to have an effect on later performance. Namely, while serum T3 concentrations were maintained, decreases in T4 reflected the first response to the demands of reproduction and were accompanied by increases in cortisol levels. As a whole the data provide support to the idea that interrelationships between all the hormonal axes form a new homeorhetic balance which reflects and possibly may be used to predict reproductive performance in sows. Since the balance may be manipulated by alterations in nutrition and other management practices, perspectives for improvement may be opened. For example, the mechanism of the negative association between basal insulin levels and piglet numbers should be further investigated.

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MOGUĆA VEZA IZMEĐU NEKIH POKAZATELJA USPEHA REPRODUKCIJE KRMAČA I KONCENTRACIJA TIREOIDNIH HORMONA, INSULINA, IGF-I, KORTIZOLA I PROGESTERONA U SERUMU

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SADRŽAJ

U cilju ispitivanja mogućnosti predviđanja reproduktivne performanse krmača, određene su konentracije hormona i insulinu sličnog faktora rasta (IGF-I) u dvadeset meleza u sredini i na kraju graviditeta, nekoliko dana posle prašenja kao i dan posle odbijanja legla. Prosečna koncentracija trijodotironina (T3) blago se smanjila od 1.31 do 1.12 nmol/1 u toku celog perioda, dok su se nivoi tiroksina (T4) snizili od 55.2 do 34.8 nmol/1 u toku graviditeta, a zatim se vratili na vrednost od 43.2 nmol/1. Bazične koncentracije insulina povećavale su se sporo ali značajno, od 3.0 do 6.9 mIU/1, dok su nivoi kortizola pokazali prvo povećanje u toku grafiditeta (66 do 167 nmol/1), a zatim pad (110 nmol/1) posle prašenja i drugo povećanje (148 nmol/1) posle odbijanja legla. Nivoi progesterona u serumu smanjivali su se blago u toku graviditeta (41 do 26 nmol/1) i onda naglo padali(1.1 nmol/1) posle prašenja osim kod jedne krmače. Ukupan IGF-I povećao se više od četiri puta posle partusa (48 do 228 mg/1), a zatim smanjio (132 mg/1).

Dobijeni podaci korišćeni su za statističku analizu u odnosu na pokazatelje reproduktivnog uspeha, kao što su broj i težina prasadi u leglu i promene telesne težine krmača. Nađeno je da su bazične koncentracije insulina u sredini graviditeta u negativnoj korelaciji sa brojem oprašenih ($r = -0.530$) i živorođenih ($r = -0.667$) prasadi. Pored toga, trećina varijanse ($R^2 = 0.33$) u težini živorođenih

prasadi predviđena je nivoima insulina negativno (P= 0.025) a progesterona pozitivno (P = 0.044) dobijenim u sredini gestacije. Pri tome, multiregresija u koju su uključeni nivoi T4 (P = 0.027), kortizola (P = 0.05) i progesterona (P = 0.1) na kraju gestacije opisala je 45% varijanse opšteg neto performansa krmača (težina prasadi pri odbijanju + neto promena u težini krmača od parenja do odbijanja legla).

Takav prilaz problemu može da pomegne u razjašnjenju uticaja promena u ishrani i načinu držanja na uspeh reprodukcije što je posledica promene koncentracija metaboličkih hormona.