Relationships of Plasma Insulin-like Growth Factor (IGF)-I and IGF-II Concentrations to Litter Size and Lactation Performance in Landrace and Yorkshire Pigs

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Landrace와 Yorkshire 돼지에서 혈장의 Insulin-like Growth Factor (IGF)-I과 IGF-II 농도와 산자수 및 비유성적과의 관계

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ABSTRACT

The present study was undertaken to find relationships of plasma insulin-like growth factor (IGF)-I and IGF-II concentrations to litter size and lactation performance. Sixty pure-bred Landrace and Yorkshire pigs having similar farrowing weeks which had been selected from a large number of pregnant gilts and sows were divided into low- ($<\mu - 0.5$ SD) and high-litter size ($>\mu + 0.5$ SD) lines under a 2 (breed) × 2 (line) factorial arrange of treatments. After adjusting the litter size to nine piglets per sow at farrowing, total litter weight was measured at three weeks postpartum at weaning as an index of milk yield. Blood samples were obtained from the jugular vein at day (d)-90 pregnancy (Px) and at d-15 postpartum. The litter size or the number of piglets born during the present experiment and the average litter size during the entire parities up to the present one were greater in the high-line than in the low-line by 3.7 and 2.4 piglets, respectively ($P<0.01$); effect of the breed on litter size was not significant. Plasma IGF-II concentration at d-90 Px was greater in the high-line than in the low-line. Litter size and d-90 Px IGF-I concentration were negatively correlated in Landrace ($r=-0.46$; $P<0.05$) and tended to be negatively correlated in Yorkshire ($r=-0.31$; $P=0.09$), which resulted in a significant negative correlation between these two variables in total animals ($r=-0.35$; $P<0.01$). Litter weight at weaning was not different between the two breeds or lines. Relationships between the litter weight and IGF concentration were not consistent across the breed × physiological stage combinations. Results suggest that d-90 Px IGF concentrations may be indicative of the litter size at impending farrowing.
(**Key words** : IGF, Litter, Pregnancy, Lactation, Pig)

Ⅰ. INTRODUCTION

The reproductive performance, mostly represented by litter size and milk yield, is a most important economic trait in swine production. Finding a physiological marker for the

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reproductive trait therefore will be meaningful as a scientific pursuit as well as a means of developing a selection index for the breeding stock. In this regard, one of the promising physiological makers for the reproductive traits is the circulating concentration of insulin-like growth factors (IGFs) on the following bases. First, the IGF is known to play important roles in follicular development (Lee, 1996; Cox, 1997), fetal growth and development (Lee, 1997) and mammary gland development and lactation (Cohick, 1998) in laboratory and farm animals. Second, circulating IGF-I and -II concentrations have been reported to exhibit a medium level of heritability ranging from 0.40 to 0.26 in the mouse (Blair et al., 1987) and pig (Lamberson et al., 1995, 1996), although the former workers subsequently reported that the heritability of plasma IGF-I concentration in mice decreased to 0.15 by the 6th and 7th generations (Blair et al., 1989). Kroonsberg et al. (1989) further reported in a related study that mice selected for high plasma IGF-I concentration exhibited a greater litter size, greater total litter and mammary gland weights than those of the low-line counterpart by 19%, 30% and 18%, respectively. Few studies have been reported in the swine, however, regarding the relationship between the circulating IGF concentration and reproductive trait. Lamberson et al. (1995, 1996) have reported that circulating IGF-I and IGF-II concentrations of growing gilts had no relation to their subsequent litter size, indicating that prepubertal IGF concentration is not reflected into later reproductive performance. More recently, Yang et al. (1999) and Yun et al. (2001) have reported that serum IGF-I and IGF-II concentrations were different between low- and high-litter size Yorkshire sows depending on the stage of pregnancy. However, relationships of the periparturient IGF concentration in plasma and the concurrent reproductive performance have not been reported in the latter studies. The present study was therefore undertaken to find the relationship between these two variables in the sow.

Ⅱ. MATERIALS AND METHODS

1. Animals

The breeding value for the reproductive trait of the breeding gilts and sows in each breed was estimated by the following BLUP animal model (Feng and Culbertson, 1997), based on reproductive performance and pedigree analysis for 24,861 heads of breeding stock which had been raised since 1990 at the Swine Breeding Center of National Agricultural Cooperatives Federation.

$$y_{ijkl} = \mu + S_i + P_j + SS_k + A_{ijkl} + e_{ijkl}$$

where

y_{ijkl} : breeding value for the litter size of the l^{th} animal of the i^{th} farrowing week at the j^{th} parity which had been mated with the k^{th} service sire,

μ : overall mean of the breed,

S_i : effect of the i^{th} farrowing week (fixed effect),

P_j : effect of the j^{th} parity (fixed effect),

SS_k: effect of the k^{th} service sire (fixed effect),

A_{ijkl}: effect of the individual animal (random effect),

e_{ijkl} : random error (random effect).

Based on the breeding value for the litter size, a total of 60 pure-bred Landrace and Yorkshire pigs which had been selected from a large number of pregnant gilts and sows having similar farrowing weeks were divided into low- and high-lines which were defined as $<\mu$-0.5 SD and $>\mu$ + 0.5 SD, respectively. The litter size was adjusted to nine piglets per sow at farrowing, after which total litter weight was measured as an index of milk yield at weaning at three weeks postpartum. Blood samples were taken from the jugular vein using the EDTA-vacutainer at day 90 of pregnancy and day 15 postpartum.

2. IGF-I and IGF-II Radioimmunoassays

Plasma was harvested from each blood sample by centrifugation and stored at -20℃ in several aliquots until assayed. The IGF-I and IGF-II were iodinated by the chloramine-T method as previously described (Lee and Henricks, 1990). Plasma IGF-binding proteins which are known to interfere with the immuno-reaction between the IGF and its antibodies were removed by the acid-ethanol extraction procedure prior to the IGF radioimmunoassay (RIA) as originally described by Daughaday et al. (1980). In brief, 0.2 ml plasma was mixed with 0.8 ml acid-ethanol solution (12.5% 2*N* HCl + 87.5% ethanol) followed by incubation for 30 min at room temperature. The incubated mixture was centrifuged for 30 min at 1,660 × *g* at 4℃, after which the supernatant was neutralized with Tris base. The neutralized acid-ethanol extract was subjected to double-antibody IGF-I and IGF-II RIAs using commercial antisera (Gropep, Adelaide, Australia) as previously described (Lee and Chung, 2000).

3. Statistical analysis

Measurements of the reproductive traits and plasma IGF-I and IGF-II concentrations at each physiological stage were analyzed by the GLM procedure of SAS (SAS Inst. Inc., Cary, NC, USA). The statistical analysis model included main effects of breed and line (low- vs high-litter size) and a breed × line two-way interaction.

Ⅲ. RESULTS

Reproductive performance traits of the experimental animals are shown in Table 1. Litter size (number of piglets born) was not different between Landrace and Yorkshire breeds. By contrast, the high-line animals gave birth to 3.7 more piglets on an average than the low-line during the present experiment ($P<0.01$), which resulted in a greater breeding value for the litter size in the former line than in the latter ($P<0.01$). The average litter size during the entire parities up to the present one also was greater in the high-line than in the low-line by 2.4 piglets ($P<0.01$). These results indicate that the division of the animals into low- and high-lines at the outset of the experiment was effective. However, litter weight at weaning, which was measured as an index of milk yield during the present experiment, was not different between the two lines or between the two breeds.

Plasma IGF-I concentration at day 90 of pregnancy (d-90 Px) was not different between the two breeds or lines, whereas IGF-II concentration was greater in the high-line than in the low-line (230±10 vs 199±9 ng/ml; $P<0.05$) at this stage (Table 2). At d-15 postpartum, a significant breed × line interaction in IGF-I concentration was detected ($P<0.01$). The high-line exhibited a greater mean IGF-I concentration than the low-line in Landrace at this stage ($P<0.01$), but such a difference was not evident in Yorkshire. It was also of note that consistent with a previous report in cross-bred gilts (Lee et al., 1993), a postpartum increase in circulating IGF-I concentration was apparent regardless of the breed or line, although the physiological stage was not included in the statistical model. In somewhat

Table 1. Reproductive performance of the low- and high-litter size female pigs

Item	Landrace		Yorkshire		P value		
	Low (n=14)[a,b]	High (n=14)[a,c]	Low (n=16)[a,b]	High (n=16)[a,c]	Breed	Line	Breed × Line
Litter size during the present experiment							
Phenotypic[d]	8.83±0.90	12.71±0.90	9.44±0.84	13.13±0.84	0.60	**	0.96
Breeding value[e]	0.08±0.11	0.77±0.11	-0.28±0.11	1.01±0.11	0.55	**	**
Avg. litter size[f]	9.90±0.42	11.78±0.11	8.99±0.39	11.91±0.39	0.34	**	0.20
Litter weight[g]	61.8 ±2.6	58.2 ±2.6	56.4 ±2.7	59.1 ±2.4	0.40	0.87	0.22

[a] Data are LS means ± SE.
[b] Selected for low-litter size.
[c] Selected for high-litter size.
[d] Number of piglets born during the present experiment.
[e] Breeding value for the number of piglets born during the present experiment.
[f] Average phenotypic litter size during the entire parities up to the present one.
[g] Total litter weight of nine piglets at weaning during the present experiment.
**, P<0.01.

Table 2. Plasma IGF concentrations of the low- and high-litter size pigs during late pregnancy and lactation

Item	Landrace		Yorkshire		P value		
	Low (n=14)[a,b]	High (n=14)[a,c]	Low (n=16)[a,b]	High (n=16)[a,c]	Breed	Line	Breed × Line
d-90 pregnancy (ng/ml)							
IGF-I	178±13	162±14	167±12	169±13	0.87	0.61	0.49
IGF-II	206±15	248±15	192±13	212±15	0.07	*	0.44
d-15 postpartum (ng/ml)							
IGF-I	411±28	301±29	342±30	389±27	0.74	0.27	**
IGF-II	140±13	120±13	141±12	146±12	0.32	0.54	0.35

[a] Data are LS means ± SE.
[b] Selected for low-litter size.
[c] Selected for high-litter size.
*, P<0.05.
**, P<0.01.

contrast, plasma IGF-II concentration, which was not affected by the breed or line at d-15 postparum, tended to be less at this stage than during late pregnancy.

Relationships between the reproductive traits and plasma IGF concentrations are shown in Table 3. Litter size had no relation to the total litter weight of nine piglets at weaning. Instead,

Table 3. Relationships of plasma IGF concentrations to the reproductive traits

	Litter size		d-90 pregnancy				d-15 postpartum			
			IGF-I		IGF-II		IGF-I		IGF-II	
	r	P	r	P	r	P	r	P	r	P
Landrace (n=28)										
Litter size[a]	–	–	−0.46	*	0.53	*	−0.24	0.22	0.13	0.60
Litter wt[b]	−0.01	0.96	0.33	0.09	−0.25	0.21	0.08	0.70	0.16	0.50
Yorkshire (n=32)										
Litter size	–	–	−0.31	0.09	0.03	0.88	0.25	0.20	0.12	0.59
Litter wt	−0.03	0.89	−0.19	0.33	0.00	0.98	−0.39	*	−0.52	**
Landrace + Yorkshire (n=60)										
Litter size	–	–	−0.35	**	0.20	0.14	−0.02	0.90	0.13	0.42
Litter wt	0.02	0.89	0.12	0.36	−0.10	0.47	−0.11	0.43	0.25	0.10

[a] Number of piglets born.
[b] Total litter weight of nine piglets at weaning.
*, P<0.05.
**, P<0.01.

this trait variable was and tended to be negatively correlated with d-90 Px IGF-I concentration in Landrace (P<0.05) and Yorkshire (P=0.09), respectively, which resulted in a significant negative correlation between these two variables in total animals (P<0.01). In addition, the litter size was positively correlated with d-90 Px IGF-II concentration in Landrace. Total litter weight at weaning was not related to either d-90 Px IGF-I or IGF-II concentration in either breed, but this variable was negatively correlated with d-15 postpartum IGF-I and IGF-II concentrations in Yorkshire. Although not shown in the table, d-90 Px IGF-I and d-15 postpartum IGF-I concentrations, but not d-90 Px and d-15 postpartum IGF-II concentrations, tended to be positively correlated.

Ⅳ. DISCUSSION

The IGF-I is a known mediator of somatotropic, gonadotropic and lactotropic hormones in growth and reproduction, although the role for IGF-II in these biological phenomena is not clear (Cox, 1997; Cohick, 1998; Lee, 2000). In line with this, circulating IGF-I concentration has been reported to be correlated with growth rate (Owens et al., 1999; Lee et al., 2002) or body weight (Lamberson et al., 1995) in growing pigs. It also has been well documented that a mouse line selected for high plasma IGF-I concentration had a greater fetal and postnatal growth rate and superior reproductive performance than the low-line and unselected control (Blair et al., 1987, 1989; Kroonsberg et al., 1989). However, such studies have not been reported in farm animal species. As an initial step to assessing the possibility of plasma IGF concentration being useful as a physiological marker for the reproductive trait, the present study was undertaken to find relationships between plasma IGF-I and IGF-II concentrations, litter size and total litter weight at weaning as an index of milk yield.

As expected, the high-line animals, chosen according to the superior record of litter size, had more piglets born than the low-line. However, the present results, especially correlation analyses, need to be interpreted with some caution, because only the high- and low-line animals were included in the present experiment. Nevertheless, it is very intriguing that the litter size was negatively correlated with IGF-I concentration at d-90 Px when circulating IGF-I concentration is lowest (Lee et al., 1993; Yang et al., 1999). There is no firm cause-and-effect explanation for this correlation at the present, but the fact that plasma IGF-I concentration declines during late pregnancy in polytocous species such as the rat (Gargosky, et al., 1990b) and pig (Lee et al., 1993; Yang et al., 1999), but not in monotocous species (Van Vliet et al., 1983; Gargosky et al., 1990a; Hess-Dudan et al., 1994; Hossner et al., 1997), provides a clue to speculating on the observed correlation. According to Gargosky et al. (1990a), pregnant rats, but not pregnant women, may need a protein catabolism during late Px to support rapidly growing fetuses resulting in a decrease in circulating IGF-I concentration. If this were the case in the rat, pregnant pigs also might need to reduce the amount of circulating IGF-I with an increasing number of fetuses. In this context, the greater IGF-II concentration in the high-line vs low-line at d-90 Px may add to the decreased IGF-I activity in the former at this stage if IGF-II could be inhibitory to IGF-I action as has been observed in sheep (Koea et al., 1992). It remains unexplained, however, why the present result on IGF-II was different from that of a previous study (Yun et al., 2001) where the d-90 Px IGF-II concentration was greater in the low-litter size Yorkshire sows than in the high-litter size.

Results on litter weight at weaning and postpartum IGF concentrations also need to be interpreted with caution, because the litter size was adjusted to nine piglets per sow at farrowing in the present study. It is therefore possible that under a natural state where sows can have varying numbers of sucklers, relationships between plasma IGF concentrations and lactation performance may be different from those observed in the present study. In lactating cows, a negative correlation between plasma IGF-I concentration and milk production has been reported (Lacasse et al., 1994). In conclusion, results suggest that d-90 Px IGF-I and potentially IGF-II concentrations in plasma bear significant information on the litter size. The relationship between plasma IGF concentration at d-90 Px and litter size at impending and subsequent farrowing, as well as the relationship of plasma IGF concentration to lactation performance under a litter size-unadjusted natural state, deserves further investigation.

V. 요 약

본 연구는 혈장의 insulin-like growth factor (IGF)-I과 IGF-II 농도와 산자수 및 비유성적과의 관계를 구명하고자 착수되었다. 분만주가 비슷한 미경산 및 경산 임신돈 중에서 선발한 총 60두의 순종 Landrace와 Yorkshire 공시돈을 저산자수 (low; $<\mu$-0.5 SD)와 고산자수 (high; $>\mu$ + 0.5 SD)-lines로 구분하여 2 (품종) × 2 (line) 요인분석 실험설계 하에 본 실험을 진행하였다. 공시돈은 분만시 모돈당 포유자돈수를 9두로 고정시키고, 3주령 이유시 비유량의 척도로서 총 이유자돈 체중을 측정하였다. 혈액시료는 임신 90일과 분만 후 15일에 경정맥으로부터 채취하였다. 본 실험기간 중 산자수 및 본 실험기간까지의 평균 산자수는 high-line이 low-line보다 각각 3.7두와 2.4두 많았고 (P< 0.01), 두 품종간 산자수 차이는 없었다. 임신 90일 혈장의 IGF-II 농도는 low-line보다 high-

line에서 높았다. 산자수는 임신 90일 IGF-I 농도와 Landrace에서는 부의 상관관계를 나타냈고 (r=－0.46; P<0.05), Yorkshire에서는 부의 상관관계 경향을 나타내어 (r=－0.31; P=0.09) 전체 공시돈에서는 이들 두 변수간 유의적인 부의 상관관계를 보였다 (r=－0.35; P< 0.01). 이유시 모돈당 총 이유자돈 체중은 두 품종간 혹은 두 lines간 차이가 없었다. 이유자돈 체중과 IGF 농도와의 관계는 품종 × 생리적인 생태 조합들간 일정한 경향을 나타내지 않았다. 이상의 결과는 임신 90일 IGF 농도가 임박한 분만시 산자수의 지표가 될 수 있는 가능성을 시사한다.

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Ⅶ. REFERENCES

1. Blair, H. T., McCutcheon, S. N., Mackenzie, D. D., Gluckman, P. D. and Ormsby, J. E. 1987. Variation in plasma concentration of insulin-like growth factor-1 and its covariation with liveweight in mice. Aust. J. Biol. Sci. 40:287-293.
2. Blair, H. T., McCutcheon, S. N., Mackenzie, D. D., Gluckman, P. D., Ormsby, J. E. and Breier, B. H. 1989. Responses to divergent selection for plasma concentrations of insulin-like growth factor-1 in mice. Genet. Res. 53:187-191.
3. Cohick, W. S. 1998. Role of the insulin-like growth factors and their binding proteins in lactation. J. Dairy Sci. 81:1769-1777.
4. Cox, N. M. 1997. Control of follicular development and ovulation in pigs. J. Reprod. Fertil. 52(suppl.):31-46.
5. Daughaday, W. H., Mariz, I. K. and Blethen, S. L. 1980. Inhibition of access of bound somatomedin to membrane receptor and immunobinding sites: a comparison of radioreceptor and radioimmunoassays of somatomedin in native and acid-ethanol-extracted serum. J. Clin. Endocrinol. Metab. 51:781-788.
6. Feng, X. and Culbertson, M. 1997. General Reduced Animal Model BLUP. Department of Animal Science, University of Georgia, Athens, GA, USA.
7. Gargosky, S. E., Moyse, K. J., Walton, P. E., Owens, J. A., Wallace, J. C., Robinson, J. S. and Owens, P. C. 1990a. Circulating levels of insulin-like growth factors increase and molecular forms of their serum binding proteins change with human pregnancy. Biochem. Biophys. Res. Commun. 170:1157-1163.
8. Gargosky, S. E., Walton, P. E., Owens, P. C., Wallace, J. C. and Ballard, F. J. 1990b. Insulin-like growth factor-I (IGF-I) and IGF-binding proteins both decline in the rat during late pregnancy. J. Endocrinol. 127:383-390.
9. Hess-Dudan, F., Vacher, P. Y., Bruckmaier, R. M., Weishaupt, M. A., Burger, D. and Blum, J. W. 1994. Immunoreactive insulin-like growth factor I and insulin in blood plasma and milk of mares and in blood plasma of foals. Equine Vet. J. 26:134-139.
10. Hossner, K. L., Holland, M. D., Williams, S. E., Wallace, C. R., Niswender, G. D. and Odde, K. G. 1997. Serum concentrations of insulin-like growth factors and placental lactogen during gestation in cattle. II. Maternal profiles. Domest. Anim. Endocrinol. 14:316-324.
11. Koea, J. B., Breier, B. H., Shaw, J. H. F. and Gluckman, P. D. 1992. A possible role for IGF-II: evidence in sheep for *in vivo* regulation of IGF-I mediated protein anabolism. Endocrinology 130:2423-2425.
12. Kroonsberg, C., McCutcheon, S. N., Siddiqui, R. A., Mackenzie, D. D., Blair, H. T., Ormsby, J. E., Breier, B. H. and Gluckman, P. D. 1989. Reproductive performance and fetal growth in female mice from lines divergently selected on the basis of plasma IGF-I concentrations. J. Reprod. Fertil. 87:349-353.
13. Lacasse, P., Block, E. and Petitclerc, D. 1994. Effect of plane of nutrition before and during gestation on the concentration of hormones in

dairy heifers. J. Dairy Sci. 77:439-445.
14. Lamberson, W. R., Safranski, T. J., Bates, R. O., Keisler, D. H., and Matteri, R. L. 1995. Relationships of serum insulin-like growth factor I concentrations to growth, composition, and reproductive traits of swine. J. Anim. Sci. 73:3241-3245.
15. Lamberson, W. R., Sterle, J. A. and Matteri, R. L. 1996. Relationships of serum insulin-like growth factor II concentrations to growth, compositional, and reproductive traits of swine. J. Anim. Sci. 74:1753-1756.
16. Lee, C. Y. 1996. Roles of the insulin-like growth factor system in the reproductive function: uterine connection. Kor. J. Fertil. Steril. 23:247-268.
17. Lee, C. Y. 1997. The role of the insulin-like growth factor system during the periimplantation period. Kor. J. Emb. Trans. 12:229-246.
18. Lee, C. Y. 2000. The insulin-like growth factor system at the interface of growth, metabolism and nutrition. J. Anim. Sci. Technol. (Kor.) 42:795-816.
19. Lee CY, Bazer, F. W. and Simmen, F. A. 1993. Expression of components of the insulin-like growth factor system in pig mammary glands and serum during pregnancy and pseudopregnancy: effects of oestrogen. J Endocrinol. 137:473-483.
20. Lee, C. Y. and Chung, C. S. 2000. Developmental patterns of circulating concentrations of insulin-like growth factor-I(IGF-I) and IGF-binding protein-3(IGFBP-3) in growing gilts and barrows: purification of IGFBP-3, development of IGFBP-3 and IGF-I RIAs and their utilization. J. Anim. Sci. Technol. (Kor.) 46:817-826.
21. Lee, C. Y. and Henricks, D. M. 1990. Comparisons of various acidic treatments of bovine serum on insulin-like growth factor-I immunoreactivity and binding activity. J. Endocrinol. 127:139-148.
22. Lee, C. Y., Lee, H. P., Jeong, J. H., Baik, K. H., Jin, S. K., Lee, J. H. and Sohn, S. H. 2002. Effects of restricted feeding, low-energy diet, and implantation of trenbolone acetate plus estradiol on growth, carcass traits, and circulating concentrations of insulin-like growth factor (IGF)-I and IGF-binding protein-3 in finishing barrows. J. Anim. Sci. 80:84-93.
23. Owens, P. C., Gatford, K. L., Walton, P. E., Morley, W. and Campbell, R. G. 1999. The relationship between endogenous insulin-like growth factors and growth in pigs. J. Anim. Sci. 77:2098-2103.
24. Van Vliet, G., Styne, D. M., Kaplan, S. L. and Grumbach, M. M. 1983. Hormone ontogeny in the ovine fetus. XVI. Plasma immunoreactive somatomedin C/insulin-like growth factor I in the fetal and neonatal lamb and in the pregnant ewe. Endocrinology 113:1716-1720.
25. Yang, S. H., Seo D. S., Park, H. B., Kim, K. D., Kang, C. W., Choi, K. S., Park, S. S., Park, S. S., Hong, K. C. and Ko, Y. 1999. Studies on the possible relationship of porcine serum insulin-like growth factor-I with litter size. Kor. J. Anim. Reprod. 23:213-220.
26. Yun, J. S., Kang, W. J., Seo, D. S., Park, S. S., Hong, K. C., Lee, C. Y. and Ko, Y. 2001. Association of endocrine factors (insulin-like growth factor-II and binding protein-3) with litter size in pigs. Asian-Aust. J. Anim. Sci. 14:307-315.

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