The prepartum sow: Consequences of stimulation with ACTH or a synthetic glucocorticoid, with observations on the liver carbohydrate metabolism of its neonates

L. A. Bate and B. Grimmelt

Department of Anatomy and Physiology, University of Prince Edward Island, Charlottetown, Prince Edward Island, Canada, C1A 4P3. *Received 27 Feb. 1990, accepted 10 Sept. 1990.*

Bate, L. A. and Grimmelt, B. 1991. **The prepartum sow: Consequences of stimulation with ACTH or a synthetic glucocorticoid, with observations on the liver carbohydrate metabolism of its neonates.** Can. J. Anim. Sci. **71**: 43–50. Twelve pregnant sows were used to determine the influence of prenatal stimulation of the adrenal glands with ACTH and the use of a synthetic glucocorticoids on the liver carbohydrate metabolism of their neonatal pigs. On the 105th day of gestation the sows were randomly assigned to one of the three following treatments: Isoflupredone injection and either ACTH or saline infusion. The sows' cortisol increased ($P<0.05$) in response to ACTH but not to isoflupredone. Glucose levels remained constant in all groups. Body weight was reduced ($P<0.05$) in piglets born to ACTH-treated sows but not in those treated with isoflupredone. ACTH treatment resulted in a reduction of body:liver weight ratio in the piglets and increase in total phosphorylase activity. Phosphorylase activity was further increased by 6 h ($P<0.05$). Liver glycogen and glucose were similar in all groups at birth and only glycogen decreased by 6 h ($P<0.05$). Thus, it is concluded that elevation of cortisol through maternal stimulation with ACTH produces a piglet which, although lighter at birth, has a lower body:liver weight ratio and a more active glycogenolytic mechanism. It is possible, therefore, that these physiological phenomena may play a successful role in maintaining neonates active until suckling.

Key words: Cortisol, liver, glucose, piglet, ACTH, isoflupredone

Bate, L. A. and Grimmelt, B. 1991. **Truie en prépartum: Effets de la stimulation par l'ACTH ou un glucocorticoïde synthétique et observations sur le métabolisme des glucides dans le foie des nouveaux-nés.** Can. J. Anim. Sci. **71**: 43–50. Douze truies gravides ont été utilisées pour déterminer les effets d'une stimulation prénatale des glandes surrénales par l'ACTH et de l'utilisation d'un glucocorticoïde synthétique sur le métabolisme des glucides dans le foie des porcelets nouveaux-nés. Au 105' jour de gestation, les truies ont été réparties au hasard en trois groupes auxquels ont été administrés un des trois traitements suivants: injection d'isoflupredone et d'ACTH ou de sérum physiologique. Le taux de cortisol des truies a augmenté ($P<0,05$) en réponse à l'ACTH mais n'a pas réagi à l'isoflupredone. Les taux de glucose sont demeurés constants chez tous les groupes. Le traitement des truies par l'ACTH a réduit ($P<0,05$) le poids corporel des porcelets, mais l'isoflupredone n'a eu aucun effet. Le traitement par l'ACTH a également provoqué une réduction du rapport poids corporel/poids du foie chez les porcelets, ainsi qu'une augmentation de l'activité de la phosphorylase totale, laquelle a augmenté de nouveau après 6 heures ($P<0,05$). Le taux de glycogène et de glucose dans le foie ont été similaires chez tous les groupes à la naissance, et seul le glycogène a diminué après 6 heures ($P<0,05$). Nous en concluons que l'élévation du taux de cortisol consécutive à une stimulation de la mère par l'ACTH produit un porcelet qui, bien que plus léger à la naissance, a un rapport poids corporel/poids du foie plus faible et un mécanisme glycogénolytique plus actif. Il est donc possible que ces phénomènes physiologiques contribuent à garder les nouveaux-nés actifs jusqu'à allaitement.

Mots clés: Cortisol, foie, glucose, porcelet, ACTH, isoflupredone

Neonatal piglets possess limited energy reserves (Seerley et al. 1974) which are difficult to mobilize immediately after birth due to impaired glycolysis and gluconeogenesis pathways (Mersmann 1974). Most of the available energy is used by the piglet to maintain homeothermic conditions during the drying process which follows birth (Mount 1968). If the piglet does not suckle soon after birth, these reserves are rapidly exhausted and the animal may become hypoglycemic (Swiatek et al. 1968). This can lead to hypothermia or lethargy and may readily result in death. In fact, 51% of preweaning mortality can be directly attributed to either starvation or crushing (Dyck and Swierstra 1987).

It has been demonstrated that prepartum stimulation of adrenal activity in the sow, with a resulting elevation in cortisol, influences the IgG absorptive capacity of the neonatal piglet (Bate and Hacker 1985a,b). The catabolic effects of glucocorticoids (Martin 1985) could reduce body weight of piglets and hence be detrimental to survival (Gardner et al. 1989). However, since glucocorticoids are also gluconeogenic (Martin 1985), it is possible that in the neonatal pig other physiological phenomena, related to energy metabolism, may be also altered by this treatment prior to parturition. Direct infusions of ACTH into fetal piglets have resulted in increased glycogen deposition in the liver (Randall 1988), while hypophysectomization of fetal pigs has reduced liver weight (Randall 1989) probably by decreasing glycogen deposits. The objective of this work was, therefore, to determine whether or not prepartal supplementation of glucocorticoids, or stimulation of the sow's adrenal gland modify liver carbohydrate metabolism in the neonatal pig.

MATERIALS AND METHODS

Twelve crossbred primiparous sows were randomly assigned to one of three experimental groups: control, ACTH or isoflupredone. On day 101 of gestation, these animals were placed in gestation stalls where they received a 14% protein commercial diet, at the same time being allowed free access to water through drinking nipples. The animals were housed in a room maintained at 18–20°C and they were exposed to 14 h d^{-1} of fluorescent light. On day 103 of gestation, the sows were catheterized through the ear vein, following the previously described technique of Bate and Hacker (1985c). The catheters were maintained functional with a saline i.v. drip (0.9% NaCl, Travenol Company Ltd., Toronto, ON) at a rate of 1 L d^{-1}. Treatment started at 08:00 h on day 105 and concluded on day 112 of gestation. Control animals were continuously infused with saline at an average rate of 1 L d^{-1}. A second group received porcine ACTH (Sigma Chemical Ltd., St Louis, MO) at a rate of 1 IU kg^{-1} d^{-1} in a similar saline infusion. The third group was injected i.m. every day with 35.7 μg kg^{-1} of isoflupredone acetate (Predef® 2X, Upjohn Inter-American Corporation, Orangeville, ON). This group also received continuous infusion of saline. The dose of ACTH is sufficient to enhance adrenal activity significantly but within physiological levels (Bate and Hacker 1985a), while the dose of isoflupredone is recommended as a therapeutic dose for pigs. All infusions were dispensed by a Gilson Miniplus 2 peristaltic pump. Daily blood samples were collected through the catheters from the sows between 08:30 and 09:00 h. Plasma was separated from these samples and stored at −20°C for later measurement of glucose and cortisol concentrations. At parturition the 1st, 3rd, and 5th piglet were weighed, bled from the suborbital sinus and isolated in a heating unit, maintained at 33–35°C (Mount 1968). They were subsequently fed 12.5 mL colostrum kg^{-1} at 30 min, 2 h, and 4 h, at which times additional blood samples were collected. At 6 h of life these piglets were sacrificed by CO_2 inhalation in a sealed chamber followed by exsanguination when the last blood sample was collected. The others of the litter had been similarly sacrificed within 2 min of birth. Piglets were weighed prior to exsanguination and their liver excised. Liver weight was recorded and the tissue was immediately frozen and kept at −75°C for subsequent analysis of glucose and glycogen content as well as glycogen phosphorylase *b*, glycogen phosphorylase *a* and glucose-6-phosphatase activity. One sow, under isoflupredone treatment, farrowed within 1 h when unobserved and accordingly its records have not been included in the study.

All animals were handled in accordance with guidelines of the Canadian Council on Animal Care.

Chemicals

Amino-N-methyl sulfonic acid (ANSA), adenosine 5′-monophosphate (AMP), cupric acetate, sodium potassium tartarate, sodium fluoride (NaF), phenol

reagent, D-glucose 1-phosphate (Glu-1-P), D-glucose 6-phosphate (Glu-6-P), glucose 6-phosphatase, phosphorylase *a* and *b*, L-Histidine, glycogen, bovine serum albumin (BSA) were all obtained from Sigma (Sigma Chemical Company, St. Louis, MO). Ammonium molybdate and potassium phosphate were purchased from BDH (BDH Inc., Dartmouth, NS). Fisher Scientific (Dartmouth, NS) provided sulfuric acid, while ethylenediamine tetraacetic acid (EDTA) was supplied by I.C.N. Biochemicals (Cleveland, OH).

Preparation of Livers

Frozen livers were partially thawed at 4°C for 2 h, and thereafter homogenized in a blender with 4°C homogenizing buffer (0.014 μM histidine, 0.002M EDTA, pH 6.5) to generate a 40% liver homogenate. The homogenate was then filtered through a 1-mm sieve and divided into nine 1.2-mL aliquots. Three aliquots were kept for glycogen and glucose estimations: a further three aliquots were mixed with an equal volume of homogenizing buffer for subsequent glucose-6-phosphatase determination. The remaining three aliquots were diluted with an equal volume of homogenizing buffer containing 0.4 μM NaF and saved for phosphorylase activity determinations. All aliquots were stored at −75°C until each specific analysis was performed.

Glucose and Glycogen

Glucose was measured with a Glucose Analyzer 2 (Beckman Inc.). This instrument uses precalibrated standards and reagents. Glycogen was estimated by means of the colorimetric reaction as used by Siu et al. (1970). Liver homogenates were diluted 50:1 with distilled H_2O. Hydrolysis of glycogen was achieved by further diluting 20 μL of liver homogenate or standards with 0.5 mL distilled H_2O, 0.5 mL of 5% phenol and 2.5 mL of sulfuric acid. Hydrolysis was allowed to proceed to completion (3 h) and the resulting absorbance measured in a Hewlett Packard spectrophotometer at 490 nm. Concentrations of glycogen were determined by interpolation of standard values with the HP-89511 quantitation software, after subtracting initial free glucose.

Glucose-6-Phosphatase

A modification of the method of De Duve et al. (1955) was used to quantify glucose 6 phosphatase. Aliquots of 100 μL of 20% liver homogenate were preincubated for 3 min in a 37°C water bath prior to the addition of 100 μL of 0.08 *M* Glu-6-P. After 10 min the reaction was stopped by the addition of 1.3 mL of 1.15% ammonium molybdate containing 3.5% sulfuric acid. The colorimetric reaction was initiated by adding 100 μL of 0.2% ANSA. The mixture was vortexed, incubated at room temperature for 10 min and centrifuged at 800 × *g* for 15 min. Absorbance was measured at 660 nm. Blanks and phosphate standards ranging from 0.1 to 1.0 μmol phosphate, were run for each assay.

Phosphorylase *a* and *b*

Phosphorylases *a* and *b* were measured by a modification of the method of Sutherland and Wosilait (1956). Fifty microliters of 20% liver homogenate was mixed with 50 μL of 14 mM L-histidine, 2 mM EDTA and 0.2 M NaF buffer. The mixture was preincubated for 3 min at 37°C prior to the addition of 100 μL of 0.036 μM Glu-1-P and 2% glycogen, and the reaction allowed to proceed for 15 min. The reaction was stopped by the addition of 1.3 mL of 1.15% ammonium molybdate, and 3.5% sulfuric acid; 100 μL of ANSA were then added and the mixture vortexed, left at room temperature for 10 min and then centrifuged at 800 × *g* for 15 min. The absorbance was measured at 660 nm immediately following centrifugation. Blanks and standards were run for each assay and the activities were calculated as μmol phosphate released min^{-1} g^{-1} tissue. Phosphorylase b was estimated in tests without the inclusion of AMP, and total phosphorylase was estimated in the tests containing 1 m*M* AMP.

Protein

Protein was determined by the method of Lowry et al. (1951). Standards made with BSA were diluted to give a range of 5–25 μg protein, and were thereafter processed along with the samples.

Cortisol

Cortisol was quantified using a solid phase RIA kit (Diagnostic Product Corporation, Los Angeles, CA). The inter- and intra-assay coefficient of variation in the laboratory were 8.3 and 7.2, respectively.

Statistical Analysis

The study was designed as a Complete Randomized Design (Steel and Torrie 1980) and the data were analyzed using General Linear Models of SAS (Spector et al. 1985). The effects of treatment, time of sacrifice, sex and respective interactions were included in the model for the analysis of each parameter measured. Differences between means were determined by Duncan's test.

RESULTS

The concentration of plasma cortisol in the sows increased ($P<0.05$) within 1 h of stimulation with ACTH, it was maintained elevated until infusion ceased on day 112, then it declined to raise again as parturition approached. Cortisol did not change in response to isoflupredone except in the hours following the first injection. Isoflupredone and control sows maintained a basal profile of cortisol which peaked at parturition (Fig. 1). Plasma glucose concentration was not modified by any treatment ($P>0.05$) (Fig. 2). Birth weight was depressed ($P<0.05$) in those piglets born to ACTH-treated sows when compared to those born to sows treated

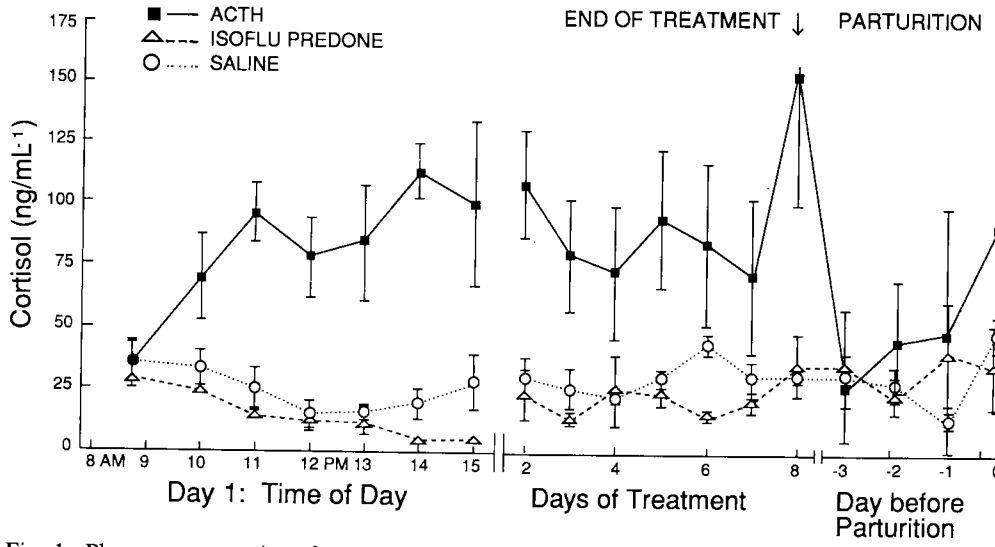

Fig. 1. Plasma concentration of cortisol in sows (mean±SE) following treatment. Arrows indicate the end of treatment on day 112 gestation and the day of parturition, respectively.

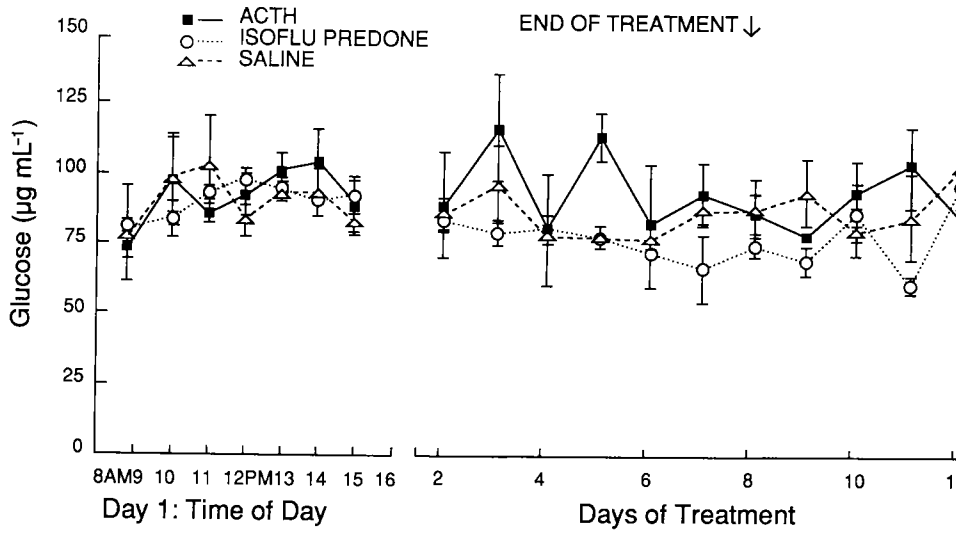

Fig. 2. Plasma concentration of glucose in sows (mean±SE). Arrows indicate the end of treatment on day 112 of gestation.

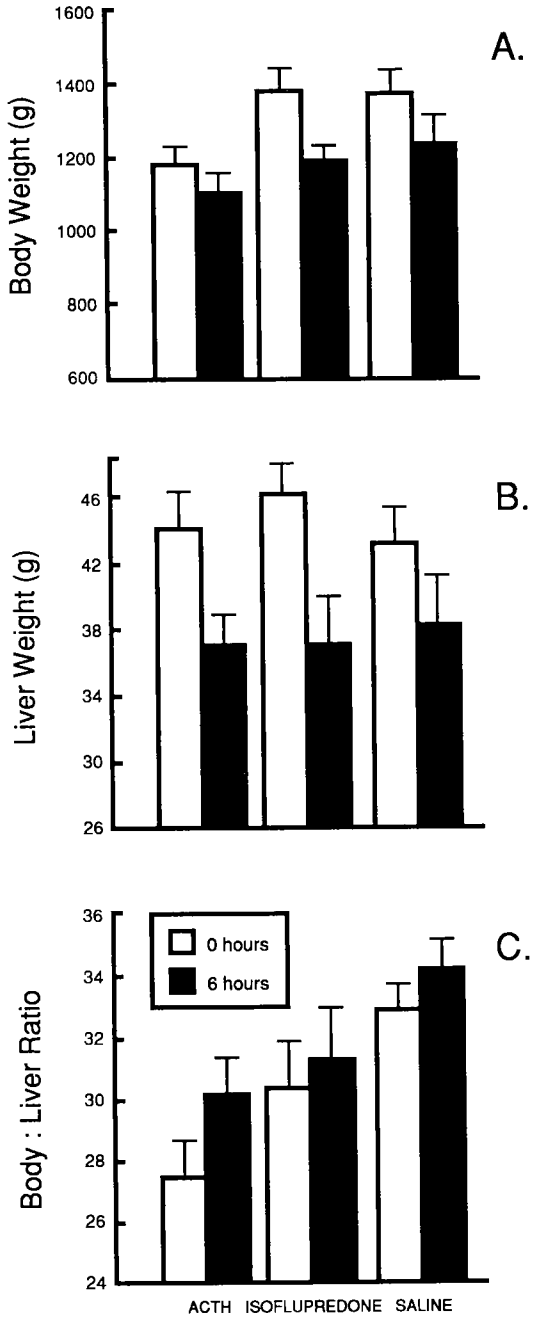

Fig. 3. Birth and 6-h weight of body and liver and the body:liver weight ratio of piglets born to sows treated with ACTH, isoflupredone or saline. Bars represent mean ± SE.

with isoflupredone or to control sows. Piglets of all groups lost weight during the first 6 h of life ($P<0.05$) (Fig. 3a). Liver weight was similar ($P>0.05$) among piglets under the different treatments, but by 6 h there was a substantial decrease in liver weight in piglets of all groups ($P<0.01$) (Fig. 3b). When body weight was taken into consideration, and the body:liver weight ratio calculated, piglets born to control sows had significantly fewer units of liver per each unit of body ($P<0.01$) (Fig. 3c).

Glycogen phosphorylase *b* as well as total glycogen phosphorylase activity of the liver was not only higher at 0 h in piglets born to ACTH- and isoflupredone-treated sows ($P<0.05$), but it was also further elevated at 6 h ($P<0.05$) in these groups (Table 1). Glucose-6-phosphatase activity was similar in piglets of all experimental groups at 0 h ($P>0.05$). However, it increased significantly ($P<0.01$) by 6 h in piglets born to ACTH-treated and control sows (Table 1).

The protein content was higher ($P<0.05$) in the liver of piglets born to control sows than in those of piglets born to sows treated with isoflupredone. Liver protein was higher at 6 h than at 0 h in all experimental groups ($P<0.05$) (Table 2). Piglets of all groups had similar glycogen content in the liver ($P>0.05$) (Table 2) at 0 h, and it decreased by 6 h ($P<0.01$).

Free glucose g^{-1} liver did not change in response to any treatment but it was relatively higher in piglets from ACTH-treated sows, when these values were expressed per unit of body weight. The plasma concentration of cortisol in piglets was not influenced by treatment ($P>0.05$), but there was a constant decline during the first 6 h of life (Table 3). The blood samples collected from piglets at the time of 0 h exsanguination had lower cortisol concentrations ($P<0.01$) than those collected from the suborbital sinus of piglets at 0 h. This was consistent in piglets of all treatment groups. A substantial elevation in circulatory glucose ($P<0.01$) was observed in all animals sacrificed at 0 h in comparison with those sampled at 0 h (Table 3). Sex differences were not observed in any of the parameters measured.

Table 1. Enzymatic activity in the liver of piglets sacrificed at 0 or 6 h[z]

Enzyme	Treatment	Time of sacrifice (h)			
		N	0	*N*	6
Phosphorylase *b* (μmol min^{-1} g^{-1} liver)	ACTH	15	2.23† ± 0.25	11	2.77†* ± 0.29
	Isoflupredone	15	2.08† ± 0.20	9	2.84†* ± 0.33
	Saline	22	1.73 ± 0.18	12	1.89 ± 0.20
Total phosphorylase (μmol min^{-1} g^{-1} liver)	ACTH	12	3.00† ± 0.25	11	3.55†* ± 0.28
	Isoflupredone	15	2.94† ± 0.26	9	3.64†* ± 0.38
	Saline	22	2.51 ± 0.23	12	2.74 ± 0.21
G-6-phosphatase (μmol min^{-1} g^{-1} liver)	ACTH	15	0.94 ± 0.16	11	1.74* ± 0.41
	Isoflupredone	15	0.97 ± 0.10	9	1.00 ± 0.15
	Saline	22	1.00 ± 0.12	12	1.64* ± 0.34

[z]Values are presented as mean ± SE.
*Within each enzyme the 6-h values are different ($P<0.05$) than values at 0 h.
†Within each enzyme values are different ($P<0.05$) than values from saline treatment.

Table 2. Glycogen, glucose and protein content of the liver of piglets sacrificed at 0 and 6 h[z]

Substance	Treatment	Time of sacrifice (h)			
		N	0	*N*	6
Glycogen (mg g^{-1} liver)	ACTH	15	74.96±6.19	11	56.28†±3.90
	Isoflupredone	15	79.82±5.40	9	68.85†±8.61
	Saline	22	81.33±3.83	12	60.58†±6.90
Glucose (mg g^{-1} liver)	ACTH	15	7.50±0.58	11	8.67 ±0.81
	Isoflupredone	15	8.21±0.33	9	7.97 ±0.63
	Saline	22	7.84±0.46	12	7.82 ±0.46
Protein (mg g^{-1} liver)	ACTH	15	62.55±1.98	11	69.45†±2.50
	Isoflupredone	15	60.74±2.00	9	64.75†±4.02
	Saline	22	65.04±2.33	12	75.12†±3.90

[z]Values represent mean ± SE.
†Values are different ($P<0.05$) than 0 h value.

Table 3. Plasma concentration of Cortisol and Glucose in piglets

Treatment	Cortisol concentration (ng mL^{-1})				
	Time and form of collection				
	0[z]	0	2	4	6[z]
ACTH	146.8*±16.5	220.2±22.3	134.1±19.3	129.4±13.9	102.1±14.5
Isoflupredone	162.0*±18.1	219.7±24.7	178.2±39.7	176.4±49.3	155.4±44.9
Control	155.2*±14.2	239.9±24.4	200.4±38.7	142.7±32.0	128.6±20.3
	Glucose concentration (mg dL^{-1})				
ACTH	198.8*±32.3	82.2±10.8	48.8± 6.9	55.0± 5.5	198.4±36.5
Isoflupredone	153.2*±29.4	44.7± 3.3	59.1± 6.6	65.7±14.3	180.1±27.6
Control	123.6*±14.9	63.1±15.0	60.8±12.4	45.4±12.9	133.9±19.0

[z]Data in these columns reflect samples collected during exsanguination of the animal.
*Values are different from values at 0 h ($P<0.01$).

DISCUSSION

The elevation of plasma cortisol observed in ACTH-treated sows during the period of infusion demonstrates successful activation of the sow's adrenal while the marginal decrease in plasma cortisol observed in isoflupredone-treated sows suggests that the synthetic compound is recognized by the glucocorticoid regulatory feedback mechanism of the sows. Changes in plasma cortisol were not reflected in modifications of the plasma glucose; therefore, it appears that the sow can maintain euglycemic status, probably by compensation with other hormones such as insulin. Elevated levels of cortisol, either maternal or fetal in origin, could be, through its catabolic properties (Martin 1985), responsible for the reduction in body weight observed in piglets in the ACTH group. The dosage of isoflupredone used in this experiment, however, may not have been sufficient to reduce body weight. Randall (1989) has demonstrated an increase in body weight and a decrease in liver weight in prenatally hypophysectomized pigs while Heath (1989) reported the opposite response in piglets subjected to cold stress. The decrease in body:liver ratio resulting from ACTH, is consistent with these findings.

The absence of differences on liver glycogen content is unclear. Glucocorticoids increase glycogen deposition in fetal animals (Randall 1988) by promoting glycogen synthase activity (Martin 1985). In this trial, the early suspension of the stimulation (day 112) may have neutralized such an effect. The elevated activity of glycogen phosphorylase could have depleted the glycogen reserves accumulated during the treatment period. If this suggestion is correct and an elevation in cortisol sustained until parturition results in higher glycogen phosphorylase at this time, then, the animals would have more reserves and a better mechanism to mobilize them. As it stands now, the ACTH piglets have no more glycogen than the controls but they have potential for faster mobilization of these reserves. Such a situation is highly desirable since low phosphorylase activity is considered one of the major metabolic defects in the neonatal piglet (Mersmann 1974). On the other hand, glucose-6-phophatase activity, which is considered abundant in the liver of neonatal piglets by Mersmann (1971), was not modified by the treatments. Therefore, the liver seems to have adequate capability to convert glucose-6-phosphate to glucose. The lack of differences between the plasma cortisol concentrations in piglets can be attributed to the process of parturition when serum cortisol concentrations are dramatically increased (Bate and Hacker 1985b). The slightly higher concentration of cortisol in samples collected from the sub-orbital sinus at 0 h in comparison to those of the piglet sacrificed at 0 h may reflect the stress resulting from holding the piglet for blood collection.

The data presented in Table 1 clearly demonstrate that the sacrificing process triggers a massive release of glucose into the circulation of the piglets, probably as a result of catecholamine release (Mersmann 1974). It therefore follows that glucose concentrations observed in animals at the time of sacrifice are an overestimation of the actual physiological concentrations at these times. Most likely, the glucose concentration at 6 h continues the decreasing pattern observed during the first 4 h of life or it gets stabilized.

From the two treatments applied, ACTH seems to be more effective than isoflupredone in enhancing liver activity and changing the body:liver weight ratio. It is possible, however, that larger dosages of an artificial glucocorticoid may trigger similar results as ACTH. These findings, combined with the fact that piglets born to sows with stimulated adrenal activity are capable of absorbing more IgG (Bate and Hacker 1985a,b), warrant further studies to determine long-term effects of such treatments on viability and potential reduction in mortality.

In conclusion, this work has suggested that enzymatic activity in the liver of the piglet, associated with the mobilization of energy resources, can be enhanced by prenatal manipulation of adrenal activity in the sow. The optimal schedule for manipulation which optimize both the energy reserves and the mobilizing capabilities remains to be established.

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Bate, L. A. and Hacker, R. R. 1985a. The influence of the sow's adrenal activity on the ability of the piglet to absorb IgG from colostrum. Can. J. Anim. Sci. **65**: 77–85.

Bate, L. A. and Hacker, R. R. 1985b. The influence of environmental temperature during late gestation and soon after birth on IgG absorption by newborn piglets. Can. J. Anim. Sci. **65**: 87–93.

Bate, L. A. and Hacker, R. R. 1985c. Effect of cannulation and environmental temperature on the concentration of serum cortisol in pregnant sows. Can. J. Anim. Sci. **65**: 399–404.

De Duve, C., Pressman, B. C., Gianetto, R., Wattiqux, R. and Applenews, F. 1955. Intracellular distribution patterns of enzymes in rat liver tissue. Biochem. J. **60**: 604–617.

Dyck, G. W. and Swierstra, E. E. 1987. Causes of piglet death from birth to weaning. Can. J. Anim. Sci. **67**: 543–547.

Gardner, I. A., Hird, D. W. and Franti, C. C. 1989. Neonatal survival in swine: Effects of low birth weight and clinical diseases. Am. J. Vet. Res. **50**: 792–797.

Heath, M. E. 1989. Effect of rearing temperature and level of food intake on organ size and tissue composition in piglets. Can. J. Physiol. Pharmacol. **67**: 526–532.

Lowry, O. H., Rosebrough, N. J., Farr, A. L. and Randall, R. J. 1951. Protein measurement with the Folin phenol reagent. J. Biol. Chem. **193**: 265–275.

Martin, C. R. 1985. Endocine physiology. Oxford University Press, Inc., New York, NY. pp. 218–219.

Mersmann, H. J. 1971. Glycolytic and gluconeogenic enzyme levels in pre- and postnatal pigs. Am. J. Physiol. **222**: 1297–1302.

Mersmann, H. J. 1974. Metabolic patterns in neonatal swine. J. Anim. Sci. **38**: 1022–1030.

Mount, L. E. 1968. The climatic physiology of the pig. Edward Arnold. London, U.K.

Randall, C. G. B. 1988. Tissue glycogen concentrations in hypophysectomized pig fetuses following infusions with cortisol. J. Devel. Physiol. **10**: 77–83.

Randall, G. C. B. 1989. Effect of hypophysectomy on body and organ weights and subsequent development of the fetal pig. Can. J. Anim. Sci. **69**: 655–661.

Seerley, R. W., Pace, T. A., Foley, C. W. and Scarth, R. D. 1974. Effect of energy intake prior to parturition on milk lipids and survival rate, thermostability and carcass composition of piglets. J. Anim. Sci. **38**: 64–70.

Siu, L. O., Russell, J. C. and Taylor, A. W. 1970. Determination of glycogen on small tissue samples. J. Appl. Physiol. **28**: 234–236.

Spector, P., Goodnight, J. H., Sall, J. P. and Sarle, W. S. 1985. SAS Institute Inc. SAS/STAT® Guide for Personal Computers, Version 6 Edition. Cary, NC.

Steel, R. G. D. and Torrie, J. H. 1980. Principles and procedures of statistics. A biometrical approach. McGraw-Hill Book Company. Toronto, ON.

Sutherland, E. W. and Wosilait, W. D. 1956. The relationship of epinephrine and glucagon to liver phosphorylase. J. Biol. Chem. **218**: 459–468.

Swiatek, K. R., Kipnis, D. M., Mason, G., Chao, K. L. and Cornblath, M. 1968. Starvation hypoglycemia in newborn pigs. Amer. J. Physiol. **214**: 400–406.