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Abstract

The period of 2-3 days following birth represents a critical period in the life of a pig. A major factor adversely affecting survival is the difficulty of the piglet to maintain homeothermy. Its thermoregulatory mechanisms available at birth become active immediately, but the thermogenesis is limited by the paucity of body energy reserves mainly composed of glycogen. Ingestion of colostrum is associated with a considerable increase in the metabolic rate wich contributes to maintenance of body temperature. Within the first day of life, it is established that both heat production and rectal temperature are closely related to the level of colostrum intake. Failure to provide an adequate thermal environment reduces colostrum intake in the neonatal pig with corresponding effects on the development of the immunological and thermoregulation system. Finally, the key role of cold stress on neonatal mortality is discussed.

Data from different countries show that preweaning losses average 15 to 20 % of live born piglets. It is noteworthy that this mortality rate should remain so high despite the great increase in knowledge in neonatal physiology, nutrition, health and management. The majority of these deaths occur during the first postnatal week with the heaviest losses being reported within 72 h of birth (fig. 1). In addition, later deaths are often triggered off by events in the first hours of life. This illustrates how critical the neonatal period is to survival and how research on all aspects of the baby pig remains a very important priority.

Many attempts have been made to identify the causes and key factors involved in baby pig mortality. Starvation leading to hypoglycaemia, diarrhea and crushing are generally reported as the main direct causes of death. However exposure to cold soon after birth is probably responsible for more deaths than any other factor. For example, a mortality rate of 6 % has been reported during the first day of life in litters that were farrowed at an environmental temperature of 25 °C. However at 10 °C the mortality rate was 31 % (Parker *et al.*, 1980). Provision of bedding considerably reduces the losses of piglets within the first four days of life (Aumaitre, 1980). In this regard it is commonly accepted that the neonatal pig is very susceptible to cold (Mount, 1968). Even at thermal neutrality, the piglets depend upon considerable mobilization of body energy reserves until such times as it achieves homeothermy and is consuming sufficient energy-yielding substrates from its diet. Thus both the thermoregulatory capacity of the piglet associated with body energy reserves at birth and colostrum intake are important since they determine the ability of the newborn to survive during the first days of life.

Thermoregulation capacity of the neonatal pig

Despite the sharp fall in rectal temperature (RT) which occurs at birth, there is no reason to believe that the thermoregulatory mechanisms available at birth do not become active immediately. Indeed, piglets born in cold conditions respond very quickly by increasing their heat production. For example, (fig. 2) at an ambient temperature of 18 °C, the metabolic rate of piglets is 30 % higher compared to that at 31 °C within the first 20 min after birth (Noblet and Le Dividich, 1981). However the pig is the most cold sensitive ungulate (Curtis and Rogler, 1970). It has a critical temperature of 33-35 °C (Mount, 1959) in comparison with the 29 °C for lambs (Alexander, 1961) and 13 °C for calves

(Gonzales-Jimenez and Blaxter, 1962). Domestic pigs, in contrast to wild pigs are virtually hairless when born (Hansen *et al.*, 1972) and subcutaneous fat is lacking (Manners and McCrae, 1963). These together with a high surface/mass exposure presumably accounts for the pig's high critical temperature. As a consequence the thermal insulation and the heat conserving capacity of the neonatal pig are very low. This is illustrated by the fact that each 1 °C decrease below the critical temperature is associated with 1.5 kJ/kg $^{0.75}$/hour increase in heat production (Noblet and Le Dividich, 1982). This compares the 0.5 to 0.6 kJ/kg $^{0.75}$/hour reported in older pigs.

Cold resistance results from coordinated mechanisms which decrease heat loss and increase heat production. Decreasing heat loss is mainly achieved by behavioural adjustments including huddling, piloerection, and postural changes. In this respect, laboratory thermocline tests show that the piglet less than 1 day old is capable of choosing an environmental temperature which is very close to its critical temperature (Mount, 1963). However in practice, the newborn piglet prefers to lie close to the udder of the dam than in the heated area during the first days of life (Titterrington, 1974).

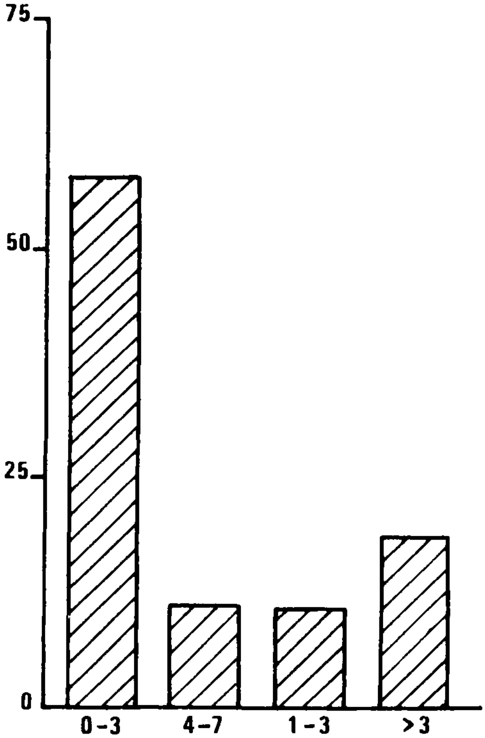

Fig. 1. — Preweaning mortality in relation to age of piglets (according to Nielson, 1981).

This behaviour undoubtedly predisposes the piglet to be overlaid by the sow. This is illustrated by the finding that the neonatal mortality is inversely related to the time spent by the piglets in the heated area (Berbigier and Le Dividich, 1978).

The inadequacy of protection against heat loss in the newborn pig increases the importance of heat production in the maintenance of body temperature. In this regard the neonatal pig has the capacity to considerably increase its heat production in response to cold. For example, its metabolic capacity to considerably increase its heat production in response to cold. For example, its metabolic temperature, is approximately four times higher than the minimal metabolic rate, i.e. 34-35 *vs* 8-9 ml O_2/kg$^{0.75}$/min (Noblet and Le Dividich, 1982; Studzinski, 1972). This metabolic capability is reached at environmental temperatures of 15-18 °C which is rather low (Nichelman *et al.*, 1975; Noblet and Le Dividich, 1982). Nevertheless, this temperature is close to the environmental temperature found in the farrowing house, unless supplemental heating and bedding are provided.

The thermostability of the fed piglet is substantially improved during the first day of life since the fall in rectal temperature in response to cold exposure is less marked in the 30 h old compared to the 6 h old piglet (Curtis *et al.*, 1967). Similarly to other newborn mammals including newborn infants (Hill and Rahimtula, 1965) and lambs (Dawes and Mott, 1959) the metabolic rate of the fed piglet is characterised by a continuous rise during the first 24 to 48 h of birth (Mount and Rowell, 1961; Gentz *et al.*, 1970; Noblet and Le Dividich, 1981). This increase is probably associated with postnatal hormonal changes. Also the specific dynamic action of colostrum is important since the successive sucklings occur near the peak VO_2 resulting from the previous suckling (Gentz *et*

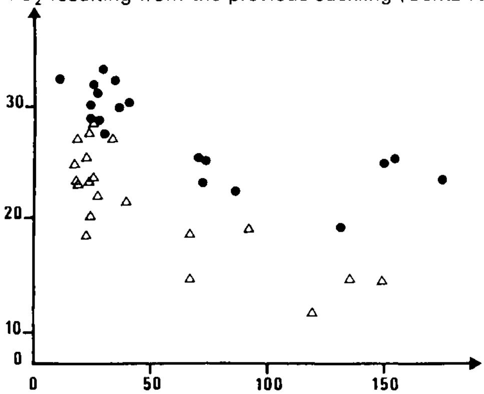

Fig. 2. — Oxygen consumption of neonatal unfed pigs kept in cold (●, 18 °C) and warm (△, 31 °C) conditions in the immediate period following birth (according to Noblet and Le Dividich, 1981).

al., 1970; Noblet and Le Dividich, 1982). In addition the availability of energy substrates may be involved in this age improvement in thermostability. In this regard it is recognized that carbohydrate are the major energy source in the period immediately following birth (Mount, 1968). However the increase in plasma FFA and in β-hydroxybutyrate levels associated with a decrease in RQ (Pegorier *et al.*, 1981; Noblet and Le Dividich, 1981) during the first postnatal day in the fed piglet, provides evidence for the early involvement of lipid metabolism. By the 2nd day of life 90 to 95 % of the energy requirement for metabolism are derived from fat catabolism (Mach and Princ, 1968).

Body energy reserves at birth

The piglet, like other newborn mammals requires energy reserves which can be mobilized at birth and will suffice until regular food intake is established. These reserves are present as triglycerides in the adipose tissue and glycogen in the liver, muscle and other tissues (table 1). The total amount of fat in the newborn piglet ranges from 1 to 2 % of the body weight. Since about half is structural fat the amount available as an energy substrate is necessarily very small. About 105 kJ/kg BW are derived from fat mobilization during a 24 h fast from birth (Seerley and Poole, 1974) which corresponds to about 25 % of the total energy expended at neutral temperature. In addition, certain fatty acids including oleic, palmitic and palmitoleic seemed to be preferentially utilized (Seerley and Poole, 1974). Recently, brown adipose tissue has been detected in the pig (Dauncey *et al.*, 1981). However, it is likely that the very small amounts found are of limited significance.

The paucity of fat stores emphasizes the importance of tissue glycogen as energy reserves. Table 1 shows the glycogen level at birth from a number of studies and demonstrates the wide range of values obtained. A 3.78 % content is reported in the whole body. From these data the total amount of glycogen stored at birth can be estimated to 30-35 g/kg BW which corresponds to 500-580 kJ/kg BW of which approximately 90 % are derived from muscle glycogen. This provides a theoretical starvation survival time of about 1.2 days assuming a metabolic rate of 13 ml O_2/min/kg BW at thermal neutrality. It is noticeable that the glycogen level in the muscle is substantially higher in the newborn pig than in other species studied (Dawes and Shelley, 1968). These glycogen stores are rapidly depleted after birth. For example, during the first 12 h postpartum, 75 % of liver glycogen and 41 % of muscle glycogen are utilized in the fed piglet (Elliot and Lodge, 1977). A low environmental temperature hastens the utilization of glycogen by increasing glucose utilization for thermogenesis (McCance and Widdowson, 1959). In this respect, the importance of shivering for thermogenesis (Brück *et al.*, 1969) suggests that the muscle glycogen is the major contributor to energy metabolism during cold exposure.

Attempts made in order to increase the energy stored in the newborn as fat or carbohydrate through maternal feeding have had variable results. Under normal conditions overfeeding of the sow or giving supplemental fat or carbohydrate during late gestation do not appear to stimulate significantly foetal fat or glycogen deposition beyond the control (see the literature in the review by Pettigrew, 1979)..Also the pregnant sow has the capability of buffering her foetuses against moderate dietary deficiencies (Etienne, 1979). A significant increase in liver glycogen stores has been found in piglets of diabetic mothers (Ezekwe and Martin, 1978). However the supplemental amount of glycogen deposited hardly meets the energy requirement of the newborn for 1 hour under practical husbandry conditions.

Nutritional importance of colostrum

The gross composition of sow colostrum is given in table 2. Crude protein is highest at farrowing while lactose and fat increase from colostrum to milk. The fat content of colostrum and milk is related to the amount of fat given to the sow (Pettigrew, 1979). For example, fat colostrum of sows

Table 1. — Tissue glycogen content in the newborn piglet.

	% of wet tissue mean (range)	Total glycogen (%)
Liver	13.7 (8.5-21)	10
Skeletal muscle	9.5 (7.2-13.7)	90
Heart	1.5	.
Whole carcass	3.1-3.7	...

According to Mc Cance and Widdowson, 1959; Swiateck *et al.*, 1968; Mersmann *et al.*, 1972; Hakkarainen, 1975; Seerley and Poole, 1974; Elliot and Lodge, 1977; Pegorier *et al.*, 1981.

Table 2. — Mean chemical composition of sow colostrum (%).

Dry matter	22.7
Lactose	4.1
Protein (N × 6.25)	11.1
Fat	6.3
Gross energy (kJ/g)	5.82

According to Noblet and Le Dividich (1982).

Table 3. — Mean increment in VO_2 and in RT in newborn piglet over a 2 h period following a single load of colostrum at 3 h of age.

Environmental temperature (°C)	32	18
Colostrum intake (g/kg BW)	33	32
Increment in VO_2 (ml/kg BW/min)	4.03	3.35
Increment in RT (°C)	0.58	0.60

According to Noblet and Le Dividich, 1982.

fed 0.18 kg supplemental fat per day during the last five days of gestation is 53 % higher compared to that of sows fed a similar amount of supplemental energy as cornstarch (Coffey *et al.*, 1982). Also the milk production is increased (Pettigrew, 1979). This has been found to be of great interest to the survival of small piglets which compete less effectively with littermates (Hartsock *et al.*, 1976; Pettigrew, 1979). Analysis of the nitrogen fraction indicates that colostrum is well balanced in essential amino-acids despite a slight deficiency in sulfur amino-acids (Duee and Jung, 1973). It is noticeable that alanine, a key glucogenic amino acid is present in high amounts in the colostrum.

Figure 3 provides evidence for the thermogenic importance of colostrum in that both body temperature and heat production are closely related to colostrum intake in cold exposed piglets (Noblet and Le Dividich, 1981). In addition partition of variance of rectal temperature between birth weight and colostrum intake indicates that the effect of colostrum intake becomes predominant from about 15 h after birth (Le Dividich and Noblet, 1981). Feeding colostrum is always followed by a postprandial rise in VO_2 and RT in both

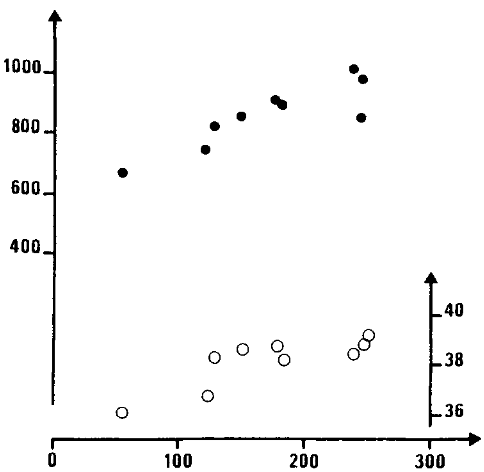

Fig. 3. — Relationship between heat production, rectal temperature and colostrum intake in piglets kept at 18 °C during the first 24 h after birth (according to Noblet and Le Dividich, 1981).

warm and cold exposed piglets (table 3) which persists more than 2 h. Thus feeding colostrum not only stops the fall in RT but also causes an increase at both experimental temperatures which suggests that the postprandial rise in metabolic rate contributes to the maintenance of body temperature.

Ingestion of colostrum results in a rapid increase in plasma glucose of the neonatal pig indicating that ingested colostrum is absorbed quickly from the gut (fig. 4). In this regard the concomitant elevation of VO_2, RQ and plasma glucose suggests that among the nutrients absorbed, glucose is quickly metabolized (fig. 4). However, the steady decrease in RQ following the rise after feeding provides evidence for a progressive contribution of non carbohydrate materials coming from either body and (or) colostrum in the energy metabolism of the neonatal pig.

Evidence for the key role of cold stress on neonatal mortality

Since the energy stores at birth are meagre and relatively independent of the nutritional and metabolic status of the pregnant sow an early and high intake of colostrum by the neonatal pig appears to be vital not only to acquire immunological protection from disease but also to insure sufficient supplies for thermogenesis and to correct blood deficiencies (Aumaitre and Seve, 1978). In this regard we have found a significant relationship between the capacity of the piglet to consume colostrum and the temperature exposure within the first day of life (Le Dividich and Noblet, 1981). At an ambient temperature of 18-20 °C commonly found in the farrowing house, the piglets consume 27 % less colostrum than their littermates kept at 30-31 °C (table 4). Very similar results are found in neonatal rabbits reared in incubators (Bernard and Hull, 1964). Also, the suckling drive may be depressed in the hypothermic newborn lambs (Alexander and Williams, 1966). Thus it is likely that in contrast to the older animals, the neonates

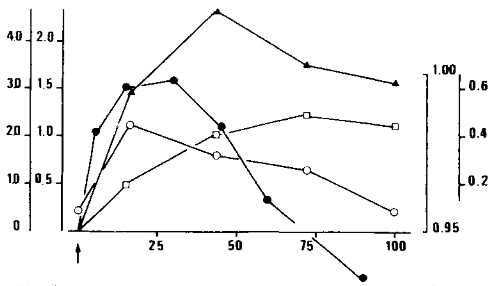

Fig. 4. — Effect of colostrum intake on RQ (○) and increment in VO_2 (▲), RT (□) and blood glucose (●) in piglets kept at 18 °C (according to Noblet and Le Dividich, 1982).

Table 4. Colostrum intake per sucking during the first day of life (g).

	Temperature		
	cold (18-20 °C)	warm (30-32 °C)	
Sucking 1-5	11.0 ± 1.2	18.2 ± 1.4	P < 0.01
Sucking 6-10	12.6 ± 1.0	15.4 ± 0.8	P < 0.05
Sucking 11-17	12.3 ± 2.0	17.6 ± 1.0	P < 0.05
Total colostrum intake through the 17 suckings	212 ± 13	290 ± 13	P < 0.01

According to Le Dividich and Noblet, 1981.

are unable to increase their food intake when exposed to cold. The reasons for this particular behaviour are not known. However it is probable that hypothermia induced by cold exposure reduces the vigor of the piglets leading to a less aggressive nursing behaviour (Hartsock *et al.*, 1976).

Thus cold stress impairs the neonatal pig's thermostability by increasing its metabolic rate and reducing the quantity of colostral nutrients available for thermogenesis. This "vicious circle" would therefore lead to chilling, hypothermia and death. In addition, the reduction in colostrum intake also lowers the level of circulating immunoglobulins (Blecha and Kelley, 1981) resulting in diminished passive antibody protection and in an increased susceptibility to disease. In this respect it has been reported that piglets which died before weaning had lower levels of colostrum derived immunoglobulins at 24 h of age than those which survived (Hendrix *et al.*, 1978). In addition, cold stress *per se* increases the incidence of infectious diseases by lowering the piglet resistance to pathogenic microorganisms as demonstrated for TGE. (Furuuchi and Shimizu, 1976) and enterotoxigenic *E. coli.* (Armstrong and Cline, 1977). The complex etiology of neonatal piglet mortality and the central role of cold stress based on this analysis is illustrated in figure 5.

Conclusions

The immediate period following birth is very critical for the survival of the young piglet. Its energy metabolism and hence its thermoregulation in response to cold exposure are limited by the paucity of energy reserves. At birth, the piglet is almost

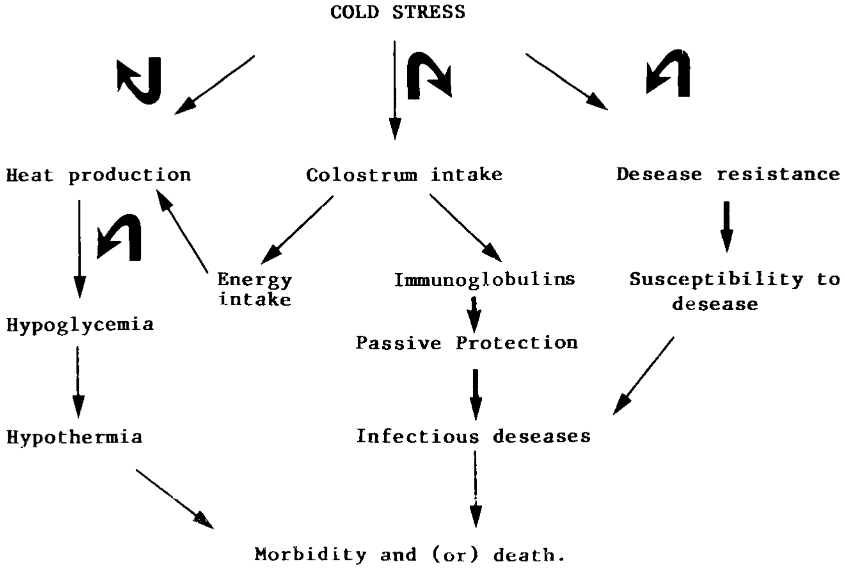

Fig. 5. — Schematic representation of the possible effects of cold on the health of the neonatal pig (adapted from Kelley, 1982, Close and Le Dividich, 1982).

totally dependent upon carbohydrate for maintenance of vital body function and thermogenesis. Emphasis is given to the effects of environmental temperature on colostrum intake and therefore on energy and immunoglobulins intake. The key role of cold stress on neonatal piglet mortality is discussed.

EEC seminar on gastro-intestinal diseases in the young pig and calf. 1-3 December 1982, INRA, CRZV de Theix, 63110 Beaumont, France.

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