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ENERGY METABOLISM AND THERMOREGULATION IN THE NEWBORN CALF

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Abstract

About half of calf losses occur during the first two days of life. Mortality rate is increased by difficult parturition and adverse climatic conditions. However, thermoregulatory mechanisms are operative at birth, these including the metabolism of brown adipose tissue, shivering and physical activity. Thermoregulation is just as effective in twin as in single calves provided that calving conditions are good. Heat production of Charolais and Salers calves was lower than that of Friesian; the difference came from a lower basal metabolic rate rather from a better thermic insulation. In dystocical calves, blood pH at birth was very low, lactataemia was two or three times higher than in eutocical calves, mobilization of body lipids was reduced and plasma thyroid hormone level were low, which can explain the lower heat production and the drop in rectal temperature. The physiological responses of calves born by caesarean parturition depend on the delay incurred during surgical removal.

Peri- and early postnatal mortality is high in calves: about 50 % of the losses occur within 24 h of birth (Kroger *et al.*, 1967). Likewise, French statistics on Charolais herds over an 11 year period and about 30 000 parturitions show that 53 % of total calf mortality takes place at birth and during the first two days of life (Lherm, *et al.*, 1983). Most of these early losses are directly due to or following upon dystocia parturitions (Laster and Gregory, 1973; Vallet and Dardillat, 1983). Furthermore, climatic factors (cold, wet and windy weather) affect the survival of weak calves, as the mortality rate is 50 % higher during winter than during spring in California (Martin *et al.*, 1975).

Birth, in fact, corresponds to a breaking of the

thermic balance of the calf, which abruptly passes from a 38.8 °C temperature *in utero* to an environmental temperature generally lower than 20 °C. Heat loss of the wet calf is directly proportional to the difference between skin and air or ground temperatures. This difference increases from one to 20 or 50 °C within a few seconds. So, the new-born calf has immediately to face a tremendous thermolysis in poor physiological conditions, especially due to hypoxia occurring during parturition. This is one of the reasons why hypothermia often takes place and may cause death of weaker calves. This paper describes the physiological responses of high vitality new-born calves (animals which respire immediately after birth, stand up and suckle soon after), the variations with breed and climatic

conditions and the thermoregulation failures of weak calves, especially dystocial calves.

Energy metabolism and thermoregulation in high vitality new-born calves

1. Variations of rectal temperature, thermolysis and thermogenesis

1.1. Variations with age

Rectal temperatures at birth are approximately 39.5 °C, that is about 0.8 °C above that of the cow (Bedel, 1943; Thompson and Clough, 1970). They decrease to 38.6 °C during the first hour of life and then stabilize at around 38.8 °C 4 or 5 h after (personal results, fig. 1). In cold exposed calves rectal temperatures increase to about 39.2 °C during the second day of life (Markovic, 1963).

In new-born calves held at 20 °C, heat production is at its highest 15 min after birth. It remains at the same level for 3 h and then decreases slowly by 30% from the third to the sixth hour of life (Thompson and Clough, 1970). This period corresponds to the evaporation of amniotic fluid and to the drying of the coat which becomes more and more insulating. Fasting heat production of calves at rest increases from the first to the third or the fifth day and decreases after one week of age (Roy *et al.*, 1957). This phenomenon could be due to the functioning of the digestive tract, liver and hematopoietic organs (Dolinin and Dolinina, 1981).

1.2. Effects of climatic conditions

Thermolysis and thermogenesis depend on climatic conditions and in particular on environmental temperature. Resting heat production of 15 h old Friesian calves held in a 37 °C water bath is minimal (19.9 ± 1.0 kJ/kg $W^{0.75}$) (personal results). It is close to the value (21 kJ/kg $W^{0.75}$) obtained by Thomson and Clough (1970) in 6 h old calves held at 20 °C. However, heat production is

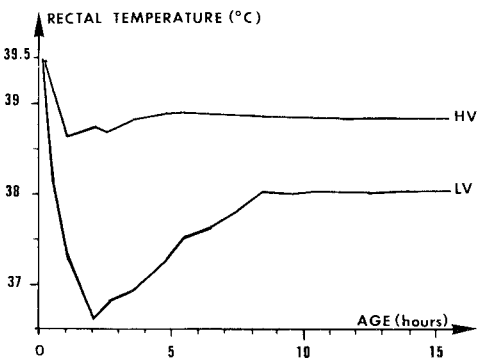


Fig. 1. — Variations of mean rectal temperature in 16 high vitality calves (HV) and 10 low vitality calves (LV) after birth.

about 70% higher at 10 °C (50 kJ/kg $W^{0.75}$ /h; personal results) than at 20 °C (30 kJ/kg $W^{0.75}$ /h) (Thompson and Clough, 1970). Similar results were obtained by Gonzales-Jimenez and Blaxter (1962) during the first day of life. However, the difference is lower (+16% or +9%) in 2 week-old calves (Holmes and McLean, 1975; Webster *et al.*, 1978).

Wind and rain influence strongly thermolysis and consequently energy requirement for thermogenesis. In three to five week-old Friesian calves, heat production was increased by 25%, 45% and 65% at environmental temperatures of 10 °C, 5 °C and 0 °C respectively (Holmes and McLean, 1975). Owing to the results obtained by Alexander (1961) in new-born lambs, the effect of wind and rain is probably much higher in new-born calves.

1.3. Variations within and between breeds

The variation in resting heat production amounts to $\pm 11\%$ between 22 Friesian calves held at 10 °C in a respiration chamber during the first day of life. This may arise from differences in external insulation, for the variation in hair coat weight (g/m^2) is $\pm 12.6\%$ between 15 Friesian calves. As a matter of fact, the variation in energy expenditure at rest of 8 new-born Friesian calves in a 37 °C water bath is only $\pm 5\%$ (personal results).

Mortality rate is much higher in twin than in single calves: 238% in the Charolais breed (Lherm, *et al.*, 1983). However, measurements in respiration chambers have shown that rectal temperature and heat production (kJ/kg $W^{0.75}$ /h) of

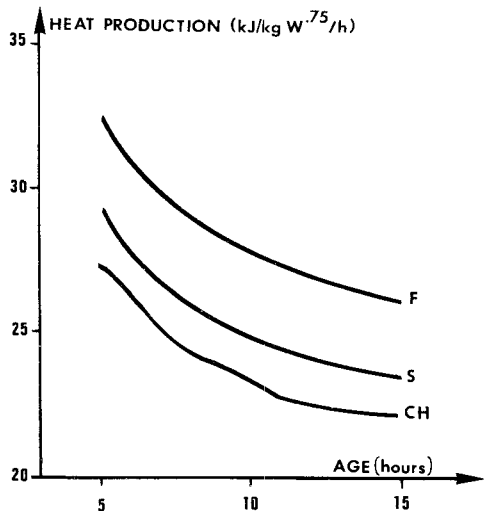


Fig. 2. — Variations of mean resting heat production of 22 Friesian (F) 10 Salers (S) and 11 Charolais (CH) high vitality calves held at 10 °C after birth.

high vitality twin and single Friesian calves held at 10 °C are not significantly different during the first day of life (personal results). Therefore, thermoregulation is as effective in twin as in single calves when they were born under favourable calving conditions.

Heat loss of young calves is not only influenced by climatic conditions but also by breed. It is 30 % higher in Jersey than in Friesian calves when exposed to wind and rain at a temperature of 0 °C. This difference may arise from lighter hair coat in Jersey calves (164 vs 350 g/m²) (Holmes and McLean, 1975). However, there is no significant difference between breeds at 20 °C.

Heat production of new-born calves held at 10 °C in a respiration chamber is 10 and 12.5 % lower in Salers and Charolais calves respectively than in the Friesian (personal results). These discrepancies could be partly attributed to the higher physical activity of Friesian calves, which spend more time standing. However, resting heat production is also lower in the Salers and Charolais calves than in the Friesian, by 10.4 and 15.5 % respectively (fig. 2). Beef calves are therefore able to maintain their body temperature in adverse conditions with a lower heat production than the Friesian calves. One would expect a better tissular and (or) external insulation, however, the weights of skin and subcutaneous adipose tissue are lower in Charolais than in Friesian new-born calves (Robelin *et al.*, 1983). Furthermore, the weight of hair coat (g/m²) is 32 % and 29 % lower in the Salers and Charolais calves respectively than in the Friesian. However, energy expenditure of resting calves in the thermoneutral zone (37 °C in a water bath) is also 13 % lower in Charolais than in Friesian calves (personal results). These differences in heat pro-

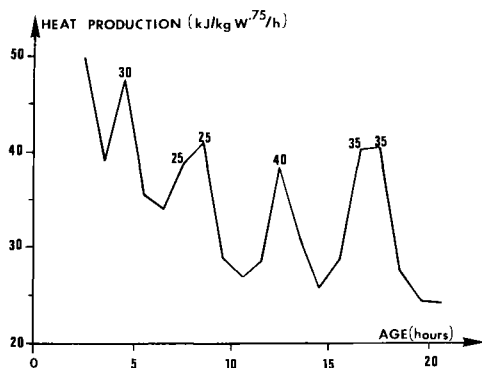


Fig. 3. — Variations of heat production of a new-born Friesian calf held at 10 °C; effect of physical activity (time spent standing, min/h) on heat production.

duction could be mainly due to differences in basal metabolic rate, associated with lower levels of plasma tri and tetraiodothyronin in the 6 h old Salers and Charolais calves (Davicco *et al.*, 1982). This result is in agreement with the lower maintenance requirement of Charolais calves and bulls at 2 and 16 months of age (Vermorel *et al.*, 1976).

2. Mechanisms of thermogenesis

Heat production of new-born animals is the resultant of several phenomena: the metabolic rate of body tissues, the metabolism of brown adipose tissue, shivering, physical activity and heat increment of feeding.

2.1. Non-shivering thermogenesis

Contrary to what was believed, new-born calves have brown adipose tissue (Alexander *et al.*, 1975; Ter Meulen and Molnar, 1975). It is located in the perirenal, inguinal and prescapular regions and amounts to about 2 % of body weight. Noradrenaline injections increase heat production for 30 min by 73 % (Ter Meulen and Molnar, 1975) on the average and up to 200 % (Alexander *et al.*, 1975). This is associated with an increase in rectal temperature of one or two degrees.

Non-shivering thermogenesis contributes probably to a large proportion of total heat production of new-born calves in the cold. However, brown adipose tissue is rapidly converted to white adipose tissue during the first month of life and reacts less and less to noradrenaline injections (Alexander *et al.*, 1975).

2.2. Shivering thermogenesis

Shivering appears soon after birth in calves held at 10 °C and stops when the hair coat is almost dry. It affects first skin muscles and rapidly skeletal muscles. In 15 h old calves lying in a 37 °C water bath, shivering starts when water temperature drops and reaches 32 °C. In spite of large between animal variations, the lower the water temperature, the more the calf shivers. Shivering is immediately followed by an increase in heat production ranging from 33 % to more than 100 % (personal results). As seen in new-born lambs, shivering seems to be a major factor of thermoregulation in new-born calves.

2.3. Physical activity

Energy expenditure corresponding to physical activity contributes also to the increase in thermogenesis (fig. 3). When a new-born calf struggles to get up, its heat production increases by 30 to 100 %. When the animal stands up for the first time and spends 10 min standing, its energy expenditure is also increased by 100 %. When it is a bit stronger and is able to stand for more than

Table 1. — Influence of calving conditions on some plasma parameters of new-born calves (mean and standard deviation).

Plasma parameters	Calving conditions (number of calves)		
	Normal (18)	Difficult (5)	Very difficult (9)
pH	7.32 ± 0.05 ^a	7.17 ± 0.07 ^b	6.98 ± 0.17 ^c
<i>Lactate (mM/l)</i>			
0 h	5.5 ± 4.2 ^a	11.3 ± 4.7 ^b	15.5 ± 2.5 ^c
2 h	3.2 ± 1.0 ^a	8.2 ± 3.2 ^b	13.4 ± 4.1 ^c
4 h	3.2 ± 0.9 ^a	6.5 ± 2.1 ^b	12.2 ± 4.4 ^c
<i>Glucose (mM/l)</i>			
0 h	4.2 ± 2.2 ^a	4.1 ± 2.4 ^a	4.1 ± 2.5 ^a
2 h	4.1 ± 1.7 ^a	4.1 ± 3.0 ^a	3.4 ± 2.8 ^a
<i>Non-esterified fatty acids (mM/l)</i>			
0 h	0.69 ± 0.28 ^a	0.50 ± 0.16 ^a	0.50 ± 0.16 ^a
2 h	1.01 ± 0.21 ^a	0.69 ± 0.21 ^b	0.69 ± 0.21 ^b
4 h	0.96 ± 0.15 ^a	0.77 ± 0.15 ^b	0.77 ± 0.15 ^b

a, b, c: values on the same line with different superscript are significantly different (P < 0.05).

30 min, heat production is increased by 40 % on average over this period (personal results).

2.4. Energy sources available for thermogenesis

Energy sources available at birth are body reserves: hepatic and muscular glycogen, labile proteins and lipids. Glycogen stores are rapidly

mobilized and broken down in the fasted calf. Glucose is used for thermogenesis and for physical activity, as shown by the increase in respiratory quotient from 4 to 6 % when the calf is struggling to stand up. Protein mobilization is probably large owing to the high levels of corticoids after birth (Olson *et al.*, 1981). One can expect that gluconeogenesis starts rapidly after birth and contributes to maintain glycemia, as was observed in new-born lambs (Warnes *et al.*, 1977).

However, glucose is probably not the major energy source in the new-born calf held at 10 °C, as the respiratory quotient is close to 0.80. Furthermore, it decreases by 3 to 13 % in 15 h old calves held in a water bath when water temperature drops from 37 to 30 °C (personal results). Body lipids are in effect mobilized, as shown by the increase in plasma non esterified fatty acids (NEFA). The latter are broken down in the brown and in the white adipose tissues and in the muscles (personal results).

When the calf is fed, colostrum constitutes an excellent energy source (6.7 MJ/kg) for thermogenesis. It supplies large amounts of glucose, amino-acids and fatty acids to the body. The nutrients are probably absorbed rapidly as immunoglobulins appear in the blood less than one hour after colostrum consumption (Olson *et al.*, 1980). In 24 Friesian calves held at 10 °C, heat production was increased on average by 18 % and 9 % respectively during the first and the second hour following colostrum consumption at 12 h of age (per-

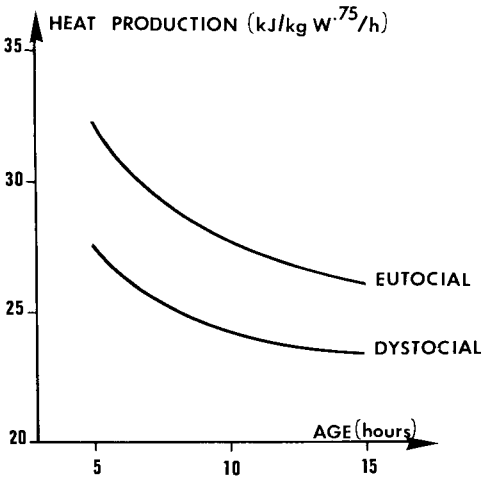


Fig. 4. — Variations of mean resting heat production of 22 eutocial and 8 dystocial Friesian calves held at 10 °C, from 5 h after birth.

sonal results). Finally, owing to heat production, an intake of 2 kg of colostrum is able to meet the energy requirement of a 40 kg new-born calf held at 10 °C for 24 h. Early consumption of colostrum is therefore very important for thermoregulation as it is for passive immunity.

2.5. Regulation of thermogenesis

Plasma tri- and tetraiodothyronin levels are high at birth and increase during the first hours of life due to TSH secretion and T4 deiodation (Davicco *et al.*, 1982). In cold stressed new-born calves cortisol, adrenaline and noradrenaline secretions are enhanced. Plasma levels remain very high up to the end of the stress (Olson *et al.*, 1981). This increases heat production considerably. On the other hand, high vitality calves move or struggle before shivering starts, at the first perception of cold (personal results). Hormonal and nervous thermoregulatory mechanisms (except peripheral vasoconstriction) are therefore well developed in the new-born calf and operative to a maximum, provided that calving conditions were good.

Energy metabolism and thermoregulation in low-vitality new-born calves

Calf mortality rate at or near the time of birth is higher after abnormal parturition (premature or dystocia). It is four times greater in dystocia than in eutocia calves and even higher in males than in females; however, mortality is similar in the case of calf pulling, posterior presentations or surgical removal (Laster and Gregory, 1973). Two thirds or three quarters of mortality arise at birth or during the first day of life (Sellers *et al.*, 1968; Petit and Menissier, 1983). After birth, these calves are weaker, less active and stand up later (Edwards, 1982; Le Neindre, 1983). We, therefore, measu-

red variations in rectal temperature, heat production and blood parameters during the first day of life in low vitality calves. The animals were either premature or obtained by calf pulling or by surgical removal (personal results).

Effects of delayed and difficult parturition (severe calf pulling)

Winter Friesian calves born in a stable were introduced one hour after birth into a respiration chamber at 10 °C. Rectal temperatures of dystocia calves dropped from 39.6 to 36.6 ± 1.3 °C within two hours after birth. Afterwards they increased slowly, reached 38 °C at 8 h of age and remained at this level, that is 0.8 °C below the rectal temperature of eutocia calves (fig. 1). Heat production ($\text{kJ/kg W}^{0.75}/\text{h}$) was significantly lower in dystocia than in eutocia calves (fig. 4). This difference decreased with age, from 25 % two and a half hours after birth to 15 %, 13 % and 10 % at 5, 10 and 15 h of age respectively.

Birth was classified into three categories: "normal" (without or with little assistance), "difficult" (calf pulling) and "very difficult" (delayed parturition and very strong calf pulling). Several blood parameters were closely related to calving difficulty (table 1). In "difficult" and "very difficult" parturitions, blood pH at birth was much lower than in "normal" parturitions, and increased slowly with time. Lactataemia at birth was two times higher in "difficult" and three times higher in "very difficult" birth than in "normal" parturitions, and decreased slowly. There was no significant difference in plasma glucose levels in spite of great variability in values, between the three groups of calves. Plasma NEFA levels were, how-

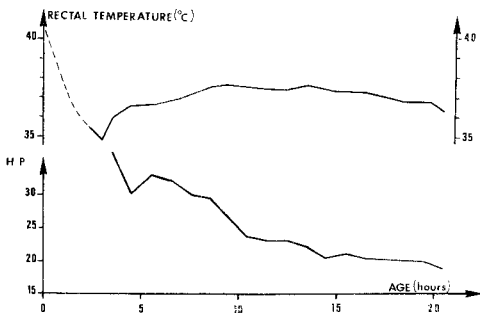


Fig. 5. — Variations of rectal temperature and heat production ($\text{kJ/kg W}^{0.75}/\text{d}$) of a dystocia Friesian calf, born by surgical removal and held at 10 °C (see text).

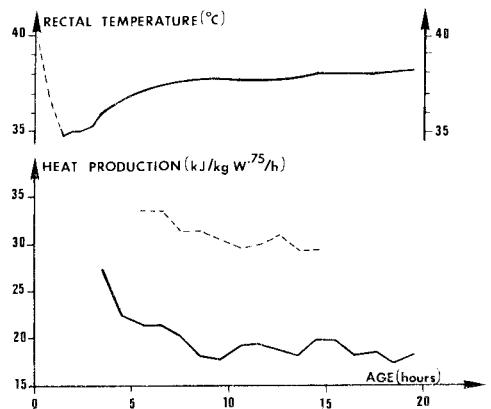


Fig. 6. — Variations of rectal temperature and heat production of a Friesian premature calf. Comparison with mean resting heat production of 22 eutocia Friesian calves (— · —).

ever, 30 % lower in "difficult" and "very difficult" than in normal parturitions. Finally, plasma thyroid hormone levels (T3 and T4) were about 40 % lower at birth, but similar two hours later. All these parameters probably explain the lower heat production and the drop in rectal temperature of calves born under poor parturition conditions.

Effects of surgical removal (caesarean parturition)

Measurements made on three calves obtained by surgical removal at term indicated marked differences in physiological response. The first one was a 56 kg Friesian calf of very low vitality. Blood pH was 7.18 at birth and decreased to 7.10 two hours later. Rectal temperature dropped to 35.5 °C and increased slowly to 37.8 °C (fig. 5). Lactataemia was high at birth (12.5 mM/l) and even higher (15.6 mM/l) two hours later. Plasma NEFA levels were, however, low. Heat production was about 12 % below the mean value of the control group.

The second calf was a 63 kg Charolais with low vitality. Both blood pH (7.32) and lactataemia were normal at birth (3.4 mM/l) as well as two hours later (1.3 mM/l). Rectal temperature dropped to 37.4 °C but increased rapidly to 38 °C two and an half hours after birth. Heat production was about 10 % lower two hours after birth and attained the same value as the control animals three hours after birth.

The third animal was a 46 kg Friesian calf with high vitality and rather low blood pH (7.25). Variations in rectal temperature, heat production, lactataemia and plasma NEFA levels were very similar to those of Friesian calves born under "normal" conditions. The physiological responses of calves born by caesarian parturition seem, therefore, to be influenced the delay of the surgical removal to hypoxia, acidosis and hyperlactataemia.

Effects of premature parturition

Energy metabolism was studied in a 25.5 kg Friesian calf of very low vitality born after 259 days of pregnancy, that is 28 days before term. Blood pH amounted only to 7.14, 7.18 and 7.28 at 0, 2 and 3 h respectively after birth. Lactataemia decreased from 8.5 to 4.4 mM/l from birth to the age of two hours. Rectal temperature dropped to 34.7 °C one and an half hours after birth, at which time the animal was covered and held at 20 °C. There was, thereafter, a slow increase to 37 °C five hours after birth (fig. 6). Heat production was only half of total and 65 % of resting heat production of high vitality Friesian calves. Plasma tetraiodothyronin level was normal, but plasma triiodothyronin level was only 25 % of that of high vitality calves at birth; the latter, however, reached the average value of high vitality calves two hours after birth.

Probable causes of the delay in the onset of thermoregulation

As in new-born lambs, the drop in rectal temperature of low vitality calves seems to be mainly due to a lower heat production. The results of studies carried out on new-born lambs permit the advancement of several hypotheses:

- severe hypoxia taking place during the expulsion phase (loosening of cotyledons, crushing of the umbilical cord) causes an intensive stimulation of the sympathetic nervous system. Catecholamin secretion is strongly increased and body reserves are rapidly mobilized and broken down, resulting in hyperlactataemia, metabolic and respiratory acidosis. Eales and Small (1980) suggested that after birth, the sympathetic nervous system is probably depressed in lambs. The absence of shivering in the low vitality calf seems to support this hypothesis. As a consequence, catecholamins and cortisol secretions (Stott and Reinhardt, 1978) are reduced and heat production restricted;

- the oxygen deficit (hypoxia) probably limits the metabolic rate, in particular in brown adipose tissue, as shown by Alexander and Williams (1970) in new-born lambs;

- cellular metabolic activity is probably also reduced by both metabolic and respiratory acidosis and hyperlactataemia.

Conclusion

High vitality new-born calves are able to face adverse climatic conditions owing to a rapid increase in heat production through brown adipose tissue metabolism, shivering, physical activity and colostrum intake. On the contrary, low vitality calves, born under unfavorable calving conditions (dystocia, premature) are handicapped by hypoxia, acidosis, hyperlactataemia as well as by a smaller mobilization of body lipids, which reduce thermogenesis. Furthermore, their physical activity is limited and they spend more time lying on the ground, which increases their thermolysis. Their body temperature, therefore drops, teat seeking activity is reduced, gastric emptying is delayed and absorption of immunoglobulins and nutrients is impaired. All these factors contribute to the high mortality rate of premature and dystocical calves during the first day of life.

The metabolic responses of the low vitality calves and the hypotheses advanced to explain the phenomena open an interesting field of research regarding treatments destined to ensure the survival and a rapid recovery of low vitality calves.

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

Résumé

MÉTABOLISME ÉNERGÉTIQUE ET THERMORÉGULATION DU VEAU NOUVEAU-NÉ. — Plus de la moitié de la mortalité des veaux se situe au cours des deux premiers jours de vie. Elle est quatre fois plus élevée en cas de vêlage difficile. Les conditions climatiques défavorables (froid, pluie, vent) augmentent la thermolyse et la mortalité des veaux. La thermorégulation est fonctionnelle dès la naissance grâce au métabolisme du tissu adipeux brun, au frisson, à l'activité physique et à l'ingestion de colostrum. Elle est aussi efficace chez les jumeaux que chez les veaux simples si les conditions de vêlage ont été bonnes. La production de chaleur des veaux Charolais et Salers est inférieure à celle des veaux Pie-Noire (fig. 2) ; la différence provient d'un métabolisme de base inférieur et non pas d'une meilleure isolation thermique. En cas de vêlage difficile, le pH sanguin est très faible, la lactatémie double ou triple de la normale, la mobilisation des réserves lipidiques est réduite (tabl. 1) et le taux de thyroxine faible à la naissance. Par suite, la production de chaleur est limitée (fig. 4) et la température rectale chute (fig. 1). Les conséquences métaboliques d'une césarienne dépendent du délai d'intervention pendant lequel s'établissent une hypoxie et une acidose plus ou moins graves. Les auteurs avancent des hypothèses permettant d'interpréter les phénomènes métaboliques et d'ouvrir la voie à des recherches sur des traitements de réanimation.

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