COMPARATIVE ASPECTS OF RESISTANCE TO BODY-COOLING

IN NEWBORN LAMBS AND KIDS

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LIST OF ABBREVIATIONS

cm	centimeter
CNS	central nervous system
°C	degree centigrade
dl	decilitre
h	hour
IRT	initial rectal temperature
kg	kilogram
KJ	kilojoule
l	litre
m	meter
mg	milligram
ml	millilitre
mm	millimeter
ng	nanogram
PMI	prematernal interest
RDRT	rate of decline in rectal temperature
RT0	"zero-time" rectal temperature
s.e.	standard error of the mean
S/E	"Starvation-Exposure-Mismothering"-complex
sec	second
STP	standard temperature and pressure
T_3	triiodothyronine
T_4	thyroxine
W	Watt
WT	live weight

Levels of Statistical Significance

NS	not significant
+	$0.05 < p < 0.1$
*	$0.01 < p < 0.05$
**	$0.001 < p < 0.01$
***	$p < 0.001$

C H A P T E R   I

INTRODUCTION

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INTRODUCTION

THE PROBLEM OF PERINATAL MORTALITY IN LAMBS AND KIDS

Fibre-producing goats are becoming an increasingly important species on New Zealand farms. There is a considerable lack of information about the physiology of goats, especially as it relates to the development of appropriate management strategies. For instance, goats are reputed to be more susceptible than sheep to cold, wet, windy conditions but comparisons between the species have not been reported. Newborn kids are thought to be very susceptible to cold-stress, but it is not clear whether this is a function of their low birth weight or some particular characteristic of the species (such as a low capacity for heat production) which leads to high mortality.

The problem of kid mortality is important from the viewpoints of both animal welfare and economic loss. The extent of kid losses in New Zealand has not been investigated, but industry sources suggest that kid mortality is high. In particular, deaths occur during inclement weather. It is expected that losses will increase with increasing goat numbers and the consequent reduction in management intensity.

Perinatal lamb mortality, defined as deaths occurring immediately before, at, or within 7 days of, birth has been recognised for many years as contributing to poor reproductive performance in New Zealand sheep flocks (Hight and Jury, 1970). Estimates of losses from birth to weaning range from 5% to 25% of all lambs born in New Zealand (Hight and Jury, 1970) and from 5% to 70% in individual Australian flocks (Alexander, 1985). Not only are the lambs themselves lost for the purposes for which they were intended (meat and/or wool production), but also the ewes produce less wool and require more feed than if they had not been pregnant. The results are lower stocking rates with in-lamb ewes and reduced selection intensity because fewer replacement animals are available (Hight and Jury, 1970).

Perinatal lamb mortality has a multiple causation including environmental, management, behavioural and disease components. There are many interactions between these and more than one factor can often be incriminated in the deaths of individual lambs.

1. Assessment of causes of perinatal lamb mortality

Perinatal mortality is readily assessed in intensive systems by counting living and dead lambs but, in extensive systems, accurate counting of dead lambs can be difficult or impossible (Alexander, 1985). Therefore, most mortality figures are given as estimates.

Two broad approaches have been used to assess the causes of lamb deaths. The autopsy approach has been used in large scale surveys in which dead lambs are collected and examined for evidence of prenatal death, predation, birth injury, breathing, walking, milk intake, fat depletion and for pathological conditions such as infection, goitre and white muscle disease (Alexander, 1985). During the last decade this approach has included examination of the extremities for evidence of oedema indicative of cold exposure, and of the central nervous system (CNS) for haemorrhages indicative of birth injury (Haughey, 1973 a, b). The autopsy approach provides a basis for classifying lambs according to the stage at which death occurred. Autopsy rarely provides evidence about the causes of starvation and provides little information about deaths from cold exposure (Alexander, 1985).

The other approach depends on direct observations of behaviour at lambing, together with measurements of temperature and weight changes of lambs. This approach is founded on a series of fundamental studies of the physiology of thermoregulation, energy expenditure and mother-young behaviour (Alexander, 1974 a, b, 1979, 1980). In recent years the two approaches have been used together.

2. Causes of perinatal lamb mortality

Most workers agree on the factors that contribute to lamb deaths, but there is still considerable controversy about their relative importance. Estimates show that 28% - 38% of all lamb deaths can be attributed to "starvation - exposure" (McFarlane, 1955; Hight and Jury, 1970), approximately 32% to dystocia, 12% to post-natal infection, 10% to pre-natal deaths and 4% to misadventure (Hight and Jury, 1970).

Both light and heavy lambs have higher mortality rates than lambs of average birthweight (Hight and Jury, 1970), although even lambs in the "optimum birth weight range" (3 - 5 kg) may still have mortality rates in excess of 10% (Hight and Jury, 1970; Dalton et al., 1980).

2.1 Dystocia

Dystocia is one of the single most important causes of lamb mortality in New Zealand and may account for up to 30% of all lamb deaths (McFarlane, 1955; Hight and Jury, 1970). Dystocia may be defined as a parturition considered likely to result in injury to the lamb or ewe and is usually associated with a long and difficult parturition (McSporran, 1975). Deaths from dystocia occur during or immediately after parturition, due to foeto-pelvic disproportion or to malpresentation (McSporran, 1975).

Lambs dying of dystocia commonly exhibit parturient lesions of subcutaneous oedema of the head and neck and internal organ damage (McFarlane, 1965). Furthermore, Haughey (1973 a, b) reported the incidence of central nervous system (CNS) lesions to be almost 100% in these lambs. Haughey (1973 a, b) also claimed that birth injury was a major factor in subsequent neonatal deaths (e.g. those commonly assumed to be due to starvation/exposure). Other workers have disputed this claim and the issue remains controversial (Alexander et al., 1980; Duff et al., 1982). However, the results of Alexander et al. (1980) showed that CNS haemorrhage was associated with reduced cold resistance in lambs. Whether the CNS haemorrhage, or the associated hypoxia and acidaemia, are the direct cause of reduced cold resistance is unclear. Difficult birth often leads to maternal exhaustion and thus can interfere with normal maternal behaviour (Alexander, 1960). This in turn can precipitate death from starvation even in the absence of birth injury.

The incidence of dystocia is highly correlated with the mean birthweight of lambs (McSporran, 1975). Birthweights over 5.5 kg are generally associated with a high incidence of dystocia (Hight and Jury, 1969, 1970),especially in single lambs. Dystocia may increase at low birthweights, presumably because of lamb weakness, poor uterine contractions of the ewes and a slow birth process (Dalton et al., 1980).

Dystocia is generally a more important cause of death in single-born lambs than in twins (Dalton et al., 1980). In a study carried out by Hight and Jury (1970), 45% of single lambs died of

dystocia compared to only 16% of twins. Similar differences in the incidence of dystocia between singles and twins have been found in other studies. Much of the birthrank effect on incidence of dystocia can be explained by differences in birth weight, singles being on average 1.0 to 1.5 kg heavier than twins (Hight and Jury, 1970). Birthrank may have an effect independent of birthweight such that twins dying of dystocia were found to be no heavier than average surviving singles. A possible explanation of this may be a higher incidence of malpresentation in twin lambs dying of dystocia (McSporran, 1977).

Male lambs show a higher incidence of dystocia because they tend to be heavier at birth (Dalton et al., 1980; Scales et al., 1986). Female survival rate is estimated to be 1% - 9% higher than that of males (Gunn and Robinson, 1963). However, the difference in birthweight between males and females is not as great as that between singles and twins (Hight and Jury, 1970).

2.2 Starvation - Exposure - Mismothering

The second largest single classification of lamb mortality in New Zealand is the "starvation - exposure - mismothering" complex (S/E), which may account for 28% to 38% of all lamb deaths (Hight and Jury, 1970). This is a very broad classification and, as a result, the most difficult to break down into its various components. The elements of starvation, mismothering and exposure

can each operate to varying extents in S/E deaths and the influences

of each are often superimposed on one another, making interpretation

of "cause and effect" relationships difficult (Duff et al., 1982).

The major post-mortem characteristics of lambs dying of S/E

are that they die between 1 and 3 days after birth, show evidence of

activity (breathed and walked), and have extensive depletion of body

reserves and a gut devoid of food (McFarlane, 1965). Alexander

(1985) states that no reliable autopsy criterion exists which shows

that death of an individual lamb has been due to cold-exposure. The

peripheral oedema, or "cold injury" described by Haughey (1973 b) is

not seen in the many lambs that die soon after birth in inclement

weather (Alexander et al., 1980), although it is seen in lambs dying

more slowly in bad weather after having suckled. Prolonged exposure

seems to be necessary for the oedema to be severe. Likewise, a fall

in body temperature in cold weather is not conclusive evidence that

death has been due to cold-exposure, because lambs debilitated for

other reasons, such as failure to suckle, show a fall in body

temperature and are prone to "chill" during progressive fasting even

in mild weather (Alexander, 1985). Consequently, diagnosis of cold-

exposure as a cause of death is largely inferential, depending on:

the association of increased mortality and declining body

temperature with cold, wet, windy weather; the appearance at autopsy

of significant numbers of lambs showing evidence of having suckled;

and oedema of the extremities (Alexander, 1980).

In large groups of lambs that appear to have died from

starvation, a minority of direct causes, such as congenital

abnormalities or severe birth injury that prevent suckling, are detectable at autopsy (Alexander, 1985). In the great majority, the causes of starvation can be assessed only by observing the flock. Some starvation deaths are due to shearing injury to the udder, or mastitis, and to delayed lactogenesis associated with ill-health of the ewe or with inadequate nutrition (McCance and Alexander, 1959). Problems with parturition, as mentioned previously, also contribute to starvation by way of maternal exhaustion or inhibition of maternal behaviour (Alexander, 1960), or because suckling behaviour of the lamb is inhibited (Haughey, 1980).

A high incidence of S/E deaths amongst lambs of low birthweight has been reported in a number of studies (Purser and Young, 1964; Hight and Jury, 1970; Dalton et al., 1980). Twin and female lambs have a higher starvation-exposure mortality rate than single or male lambs (Purser and Young, 1964). The reduced survival ability of twins is almost certainly a result of their lower birthweights,since their survival is comparable to that of surviving singles when compared at a common birthweight (Dalton et al., 1980).Also Whatawhata work shows that if twins are born on a steep slope they frequently become separated at birth and only one may be reared. Conversely Eales et al.(1982) have suggested that birthrank may have an effect independent of birth weight.

2.3 Other causes of lamb mortality

Other causes of perinatal mortality include: lethal congenital malformations, which account on average for less than 1% of total losses; specific nutritional deficiencies with sporadic outbreaks, sometimes severe, occuring in fairly well defined geographical areas; a variety of infections (some acquired in utero, others acquired after birth); and predation and misadventure, together responsible for about 4% of all lamb deaths (Haughey, 1975).

These will not be further discussed here as they comprise, with rare exceptions, less than 20% of the total mortality (Hight and Jury, 1970; Haughey, 1975).

3. Possible causes of perinatal kid mortality

Published work on perinatal kid mortality is relatively difficult to obtain. The few established factors known to contribute will be reviewed here and inserted, where appropriate, into the general overview on lamb mortality.

Many scientists have reported that kid losses are highest at parturition and just after birth (Peaker, 1978; Adu et al., 1979; Chawla et al., 1982). In France, more than 50% of total kid losses occur at birth and 75% of all kid mortality occurs within 2 days post-partum (Mohrand-Fehr, 1984).

In goats low birth weight has been reported to be the most frequent cause of mortality in the period from birth to 2 days post-partum, because of a lack of maturity of light kids (Mohrand-Fehr, 1982). It has been suggested that immature animals are deficient in circulating cortisol, triiodothyronine (T_3) and thyroxine (T_4) (Cabello and Levieux, 1981). As will be described later, thyroid hormones play a prominent part in the thermoregulation process. At birth, the thermoregulatory capacity of low weight kids is reduced because fat reserves are more limited. Moreover, the thermal losses per kilogram of liveweight are higher in light kids than in heavy kids. Consequentely, low energy reserves decrease survival time of light kids when they are fasted and mortality rates increase markedly in difficult environmental conditions such as low temperature, wind or draughts (Mohrand-Fehr, 1987).

Weak kids first stand later than others. Their chance of being groomed by their dams and of suckling colostrum is reduced, which further decreases their cold-resistance and subsequent resistance to disease. This delay in rising and suckling does not increase linearly with decreasing newborn kid weight, but is reported to appear below a certain weight limit (about 3 kg birth weight for Alpine kids) (Mohrand-Fehr, 1987).

Kid losses are influenced by two additional factors, namely duration of gestation and litter size. In Alpine goats, a 4 day shorter duration of pregnancy increased the frequency of neonatal mortality by about three times and losses were about four times more frequent in triplet births than in twin births (Mohrand-Fehr, 1985).

Increasing litter size is associated with decreased kid viability, for two primary reasons. As litter size increases, birth weight of individual kids decreases. Furthermore, increased litter size strains the capacity of many non-dairy goat breeds to provide adequate colostrum for their offspring (Sherman, 1987).

Many investigators have looked at comparative mortality rates of male and female kids, but results vary to the point that no firm conclusions can be drawn (Sherman, 1987).

Unfortunately, the few studies on kid mortality originate to a large extent from France where the majority of goats are milking or meat types which are kept indoors to kid under close supervision. Accordingly, these results cannot be applied directly to New Zealand conditions, where fibre-producing goats kid outdoors, often with minimal supervision. Given the lower birth weights and the greater litter sizes in goats as compared to sheep, and considering the above-mentioned factors which influence neonatal lamb mortality, it seems reasonable to assume that, under New Zealand conditions, the majority of kid deaths are likely to be due to S/E rather than to difficult births or diseases.

4. Physiology of Starvation - Exposure - Mismothering deaths

4.1 The Starvation - Exposure - Mismothering - Syndrome

Almost all lambs will survive if given adequate obstetrical assistance, warmth and food (Alexander et al., 1959; Alexander and Petersen, 1961). This demonstrates that survival is seldom limited by some major hereditary fault and that failure of the dam to exhibit appropriate behaviour, or failure of the newborn lamb to respond appropriately to conditions of environmental stress, are the main causes of perinatal mortality.

At birth the lamb is delivered in a physiologically advanced state from the warm uterine environment (about 39°C) to a much colder external environment. The environmental temperature may vary from about 15°C down to 0°C or effectively below -10°C, if the cooling effects of wind and rain are taken into consideration. However, wet newborn lambs start losing body heat at "still-air" temperatures below 28°C (Haughey, 1975).

Immediately after birth the lamb is faced with increased energy demands for activities not required to the same degree (or at all) in utero (e.g.heat production, walking, suckling), as well as being deprived of the maternal nutrient supply via the placenta. Therefore, the ability to maintain a high metabolic rate, rapid establishment of a bond with the dam and successful suckling are critical for survival.

Initially the rectal temperature of the newborn lamb is higher than that of its dam. This difference is associated with the higher intra-uterine temperature of the ewe (Alexander and McCance, 1958). Immediately after birth a fall in rectal temperature is usually observed. It appears that the lower the environmental temperature at the time of parturition, the greater is the fall in rectal temperature and the greater the time required for rectal temperature to return to normal (Smith, 1961). Many lambs recover their body temperature within a few hours but, in others, the decline continues until their rectal temperature falls below 37°C (Alexander and McCance, 1958).

In order to maintain a stable deep body temperature and to combat the effects of a cold environment, the lamb reduces heat loss (through constricting blood flow to the extremities and through postural changes) and increases its heat production (through shivering and burning brown adipose tissue) (Alexander, 1962 a, b). Immediately after birth the lamb is forced to increase its rate of body heat production by up to fifteen times the foetal level, to compensate for body heat loss to the environment (Alexander 1962 b). However, this increase in heat production causes the lamb to deplete its limited reserves of energy. These are mainly in the form of lipids (60 - 70%) and glycogen (15%), the remainder being derived from protein catabolism (Alexander, 1974). The lamb's energy reserves amount to a mere 4000 KJ (Alexander, 1974 a). Metabolic rates of lambs range from about 72 KJ h^{-1} (20 W) at thermoneutrality to about 360 KJ h^{-1} (100 W), representing the maximum thermogenic effort, or about 180 KJ h^{-1} (50 W) representing the rate sustainable

in the cold. Thus energy reserves may be exhausted after about 3 days in thermoneutral conditions and after about 10 hours or less in the cold (Alexander, 1962). Replenishment of energy reserves is therefore imperative if the lamb is to survive for longer periods than these.

The lamb is completely dependent on maternal milk supply for provision of metabolic substrates. However, its ability to establish and maintain successful suckling may be compromised by environmental stresses which lead to a decline in deep body temperature. Alexander and Williams (1966 a) demonstrated that the lamb's suckling reflex is markedly depressed when deep body temperature falls below 37°C so that even mild hypothermia, while in itself non-lethal, may predispose to death by starvation. In addition, Alexander and Williams (1966 a) demonstrated a possible effect of "discomfort" due to cold-exposure which, while apparently independent of the hypothermia effect, also decreases the vigour of the suckling drive. These effects are compatible with field observations that the average time from birth to first suckling is prolonged in lambs born in cold, windy conditions compared with those born in less severe environments (McBride, Arnold, Alexander and Lynch, 1967). Thus cold-exposure can accelerate death by starvation as well as cause acute hypothermia.

Alexander and Williams (1966 a) also found that early success in teat-seaking activity was important since the drive to suckle declines with age. If successful suckling is not established, and the lamb's body reserves are thus not replenished, the capacity

for heat production declines and rectal temperature falls. This in turn accelerates the lamb's susceptibility to cold-stress, deep body temperature falls even further, and the lamb may die at body temperatures below 30°C (Alexander and McCance, 1958).

According to Eales et al. (1982) there are two ages at which hypothermia is most likely to occur. In the first period, from birth to five hours post-partum, the major cause of hypothermia is excessive heat loss, presumably related to exposure of the wet newborn lamb to inclement climatic conditions. Some lambs become hypothermic because of depressed heat production related either to severe hypoxia during birth or to immaturity. Depletion of energy reserves is not a characteristic of lambs becoming hypothermic during this period. Hypothermia in the second period, from 12 to 36 hours post-partum, is associated with starvation, depleted energy reserves and a low rate of heat production.

4.2 Factors affecting the lamb's ability to suckle

There are many reasons for failure of the lamb to suckle successfully, including failure of the ewe to bond with her lamb(s), accidental separations after bonding (Alexander, 1980), udder defects such as shearing injury or mastitis (Quinlivan, 1968), delayed lactogenesis usually of nutritional origin (McCance and Alexander, 1959), competition with litter mates, birth problems that affect behaviour of the ewe and/or the lamb, congenital abnormalities, severe birth injury and cold-stress (Alexander, 1974).

4.2.1 Maternal behaviour

The essential feature of maternal behaviour is the rapid development by the mother of a bond with her young, to the exclusion of other young. Various aberrant behaviour patterns of ewes can hinder this and so negatively affect lamb survival. These include: limited grooming ability, failure to co-operate with suckling attempts (butting and rotating away from the approach of the lamb, as often occurs in young and inexperienced ewes), preferences towards litter-members, rejection of offspring, desertion and premature maternal interest (PMI) (Holmes, 1975).

Of these desertion is associated with prolonged parturition, high birth weight of lambs and excessive body condition of the ewe, these three factors being interrelated. Undernourished ewes are frequently exhausted by parturition and remain recumbent for some time; the lamb sometimes wanders away and becomes lost before the ewe can get to her feet (Alexander, 1964). Exhaustion and injury can prolong the establishment of the essential ewe-lamb relationship and adversely affect the lamb's teat-seaking activity. Bonding of ewe and lamb(s) is assisted by grooming(e.g.licking of the lamb by the ewe) and through co-operation with suckling attempts of lamb(s) (Alexander et al., 1983 a).

Pre-lambing maternal interest often leads to mismothering of lambs born to other ewes (Welch and Kilgour, 1970). Because the newborn lamb is a source of attraction to ewes nearing or just completing parturition, and the ewe and her lamb(s) are unable to

discriminate each other from other ewes and their offspring, problems of lamb-stealing and desertion arise.

Aberrant behaviour which leads to delays in establishing the vital ewe-lamb bond and delays or prevents successful suckling, will increase the susceptibility of the lamb to the influences of cold and starvation. This may in turn have an adverse effect on lamb behaviour, thus creating a vicious circle (Duff, 1981).

4.2.2 Central nervous system injury

Haughey (1973 b ; 1978) has suggested that the starvation - exposure syndrome is merely a secondary cause of lamb mortality, the primary cause being damage to the lamb's central nervous system (CNS) sustained during the birth process. In lambs which survive the birth process, the primary effect of CNS damage is apparently a depression of the suckling drive. Haughey (1975) states that this effect is more pronounced under conditions of cold-stress.

Other workers (Alexander et al., 1980; Duff et al., 1982) have disputed the finding of Haughey (1973 a, 1975) that approximately 60% of lambs assigned to the starvation-exposure mortality class have CNS lesions. Duff et al. (1982), in a New Zealand study, found that only 34% of lambs assigned to the starvation-exposure classification exhibited CNS lesions and that severe lesions were rarely seen in this group. The extent to which CNS injury is an important determinant of starvation-exposure

mortality therefore remains controversial and warrants further investigation.

4.2.3 Cold - stress

As mentioned above, cold-stress affects the lamb in two ways. First, it forces the lamb to increase its metabolic rate and thus to more rapidly utilise its limited energy reserves. If these reserves are not replenished deep body temperature falls. Second, cold-stress may then prevent the replenishment of these reserves by reducing the lamb's mobility and inhibiting the suckling drive, which in turn can cause an adverse effect on maternal behaviour. Thus, as a result of cold-stress, the lamb may enter a vicious circle of falling heat production, falling deep body temperature, supressed suckling drive, starvation and/or mismothering. The ability of the newborn lamb to maintain deep body temperature above 37°C is therefore critical for its survival.

5. Factors affecting the lamb's susceptibility to hypothermia

5.1 Heat production

Since newborn lambs have a low capacity for body heat storage (Alexander, 1961), one of the main ways in which the lamb can combat the effects of cold is to increase its heat production or metabolic rate. Metabolic rate may be classified into two categories: "Basal" metabolic rate (the rate of metabolism recorded at rest under thermoneutral conditions) and "Summit" metabolic rate (maximum sustainable metabolic rate achieved in response to acute cold-exposure).

Thermoneutrality of the dry newborn lamb is in the region of $25°-30°C$, where metabolic heat production is about $60-70$ W m^{-2} (Alexander, 1979).

5.1.1 Level of summit metabolism

The level of summit metabolism attained by the newborn lamb is an important determinant of neonatal survival since it provides the limit to which body heat loss (per unit body weight) may increase before hypothermia occurs.

The maximum level of metabolism which lambs can achieve in response to cold within the first days of life is given by Alexander(1974) as 20 W kg^{-1} (28 W $kg^{-0.75}$) irrespective of the weight of the lamb. In normal lambs from adequately fed ewes, summit metabolism, which is about five times the basal rate, may be achieved within minutes of birth (Alexander, 1974).

Exposure of newborn lambs to extreme cold causes an increase in metabolic rate to three or four times the minimum resting level of metabolism (Alexander, 1962). This increase results from both shivering thermogenesis in skeletal muscle and non-shivering thermogenesis, apparently in brown adipose tissue. Shivering and non-shivering thermogenesis together contribute to the summit metabolic response of lambs less than one week old (Alexander and Williams, 1968).

In newborn lambs all of the adipose tissue appears to be of the brown variety but it is gradually replaced by white adipose tissue in the first weeks of life (Gemmel et al., 1972). This change is accompanied by, and may be responsible for, a decline in the level of summit metabolism per unit bodyweight attained by the lamb as it ages (Alexander, 1962 b). Dissection of newborn lambs of several breeds has shown that brown adipose tissue constitutes about 1.5% of the body weight, with the largest amount being in the abdominal and cervical regions. These are the principal sites of the non-shivering thermogenesis that has been estimated to contribute about 33% of the maximum metabolic response to cold (Alexander and Bell, 1975).

The balance of the maximum metabolic response to cold is due to the effects of shivering. Shivering thermogenesis occurs in the striated muscles of the body (Alexander and Williams, 1968). Normally shivering becomes obvious only under conditions of extreme cold, which has lead Alexander (1975) to suggest that, in the lamb, shivering may not be employed until non-shivering thermogenesis is approaching its full potential. However, since striated muscle may respond to increased requirements for body heat production simply by increasing muscle tone, "shivering" thermogenesis may occur even when shivering is not observed.

Subjecting lambs to environmental conditions which evoke a summit response to heat production results in a number of metabolic changes. These include the elevation of plasma concentrations of glucose, free fatty acids, glycerol and lactate (Alexander, 1962 b; Alexander, Mills and Scott, 1968; Alexander, Bell and Hayes, 1972). Similar effects are observed in lambs exposed to less extreme cold (Alexander and Mills, 1968). The increases in the plasma levels of glucose, free fatty acids and lactate caused by cold stress are mimicked by the infusion of catecholamines into lambs under thermoneutral conditions and may be prevented in lambs exposed to cold stress by the use of adrenergic blocking drugs (Alexander et al., 1968).

Other changes which accompany induction of a summit response in metabolism include the elevation of cardiac output, depth of respiration and blood pressure; disturbance of the blood acid-base status and a redistribution of blood flow in favour of the

thermogenic tissues (Alexander and Williams, 1970; Alexander, Bell and Hales, 1972 , 1973).

Feeding is of immediate survival benefit to the newborn lamb. Eales and Small (1981) found an increase of nearly 20% in summit metabolic rate in fed lambs as opposed to unfed lambs, which would result in a reduction of the lower temperature survival limit of the lambs by approximately 10°C (Alexander, 1962 a). However, there is little published information on substrate utilization in newborn lambs. Protein does not seem to be a significant energy substrate (Alexander, 1962; Eales and Small, 1981). It appears that lipid utilization is quantitatively more important than carbohydrate utilization (Eales and Small, 1985). However, Eales and Small (1985) suggest that the newborn lamb has a greater dependence on carbohydrate as a substrate for heat production than does the adult sheep which can depend almost entirely on lipid (Bennett, 1972). A restricted ability to utilize relatively abundant lipid reserves (2-3% of body weight; Alexander and Bell, 1975) and a dependency on relatively sparse body carbohydrate reserves (1% of body weight; Shelley, 1960) would appear to severely limit the newborn lamb's ability to maintain its body temperature.

The increase in metabolic rate from basal to summit metabolism is positively correlated with the associated increases in plasma concentrations of glucose, glycerol, free fatty acids and the blood concentrations of lactate (Eales and Small, 1980). This

suggests not only that plasma catecholamine concentrations increase during summit metabolism but also that the increase in metabolic rate is related to the increase in plasma catecholamine concentration and thus to the level of sympathetic nervous activity (Eales and Small, 1980).

Other studies have suggested that summit metabolism may be limited by the supply of oxygen to the thermogenic tissues, since summit metabolic rate has been shown to be significantly correlated with such parameters as cardiac output, heart rate and respiratory frequency (Alexander and Bell, 1975 a). Alexander and Williams (1970 b) demonstrated that increasing the oxygen content of air inspired by lambs resulted in an increased level of summit metabolism in some lambs and an improved ability to maintain summit metabolism in others. These effects tended to be reversed under conditions of hypoxia. Severe hypoxia may result in depressed heat production by up to 66% (Eales and Small, 1980, 1985) and immaturity is commonly associated with depressed heat production capacity (Dawes and Pary, 1965).

The thyroid gland is highly significant in influencing metabolic rate (Slee, 1978), but little attention has been given to the role of thyroid hormones in the response of newborn lambs to cold stress (Alexander, 1970). It is generally assumed that thyroid function plays a greater part in adaption to a prolonged cold exposure than in short term thermoregulation. However, it has been

shown that triiodothyronine (T_3) administration is able to increase heat production significantly in the newborn lamb within one hour of administration (Andrews, Lynch and Moore, 1979). Cabello (1983) suggested that the thyroid hormones influence short-term thermogenesis in the newborn lamb. He found positive relationships between rectal temperature and plasma T_3 concentrations at 30 minutes post-partum (spontaneous neonatal cooling) and during neonatal exposure to cold. In the latter instance lambs dying of hypothermia did not show any evidence of the thyroid hyperactivity observed in all other animals. Klein, Reviczki and Padbury (1984) have reported that T_3 administration to the ovine foetus enhances the norephinephrine stimulation of oxygen consumption by adipose tissue. Therefore, the thyroid hormones could affect neonatal non-shivering thermogenesis by altering the lipolytic responsiveness to catecholamines. Caple and Nugent (1982) subjected newborn lambs to cold stress in a progressively cooled waterbath and observed a significant positive relationship between plasma T_4 concentration and the time taken for the rectal temperature of lambs to decrease to 35°C.

Newborn lambs have higher plasma thyroxine concentrations than their mothers, if the ewes have adequate iodine nutrition. Lambs born with goitre, due to iodine deficiency, may have plasma thyroxine (T_4) levels lower than those of their mothers and are particularly susceptible to cold stress (Caple and Nugent, 1982).

5.1.2 Rate of attainment and maintenance of summit metabolism

Rapid attainment of a high level of summit metabolism immediately after birth greatly enhances the lamb's chances of survival. Little is known about the factors affecting the rate at which summit metabolism is attained although Alexander (1962 b) has commented that poor pre-natal nutrition of the lamb appears to lead to a slow attainment of high metabolic rates immediately after birth. The final level of summit metabolism achieved is, however, independent of pre-natal nutrition.

Many of the factors which influence the lamb's ability to maintain a high level of summit metabolism have already been mentioned above. To summarize, Alexander (1962 b) has reported that declining summit metabolism (per unit body weight) may be associated with: falling deep body temperature (below 36°C), increasing lamb age, and with prolonged starvation.

5.2 Heat loss

5.2.1 Birthcoat characteristics

The heat loss from a lamb depends on its thermal insulation as well as on the environment. Differences in the thermal insulation provided by different types of birthcoat have been observed. Lambs with long hairy coats can withstand cold temperatures better than

lambs with short coats. Resistance to cold stress increases with coat depth (McCutcheon et al., 1983 b). Wetting of the coat reduces this advantage considerably (Alexander, 1958). McCutcheon (1983 a) stated that wetness was the single most important factor determining whether or not lambs became hypothermic. Wet lambs suffered a reduction in coat insulation, principally as a result of reduced coat depth, but this was a small effect compared with the increase in evaporative heat loss which occured as a result of wetting.

In a study by Samson and Slee (1981) it was found that the cold resistance of lambs chilled in a water bath was related not to the coat depth but to the weight of wool per unit area of skin. Presumably coat insulation affected cold resistance by trapping air between the water and the skin surface, or by preserving a warmer layer of water next to the skin, during the early stages of cooling. The effectiveness of this type of insulation was apparently reflected more by coat weight than by coat depth.

Small lambs tend to have shorter and sparser coats than large lambs, owing largely to failure of 'secondary' skin follicles to mature and produce wool fibres. The thermal insulation of the coat of small lambs is therefore low so that, per unit of surface area, small lambs tend to exchange heat more rapidly with the environment than large lambs. In a study by McCutcheon et al. (1983 b) twins exhibited lower coat depths (by 1.1mm at each measurement site) than singles.

Observations by Alexander (1982 a) suggest that the birth coats of lambs which have dried, but are then re-wetted, tend to trap air better than the coats of lambs still wet with amniotic fluid. The drying of the coat immediately after birth may therefore have important consequences for its insulative value.

5.2.2 Peripheral vasomotor control

The rate of blood flow from the deep body to the peripheral tissues influences the rate of heat loss because blood flow results in convective heat transfer. The thermal effects of changes in cutaneous blood flow are seen most readily in the extremities of the body. Sophisticated techniques have been used to measure the rates of blood flow through different parts of the body (Alexander et al., 1973). The most significant results in animals exposed to cold conditions were: large increases in rates of heat production, total cardiac output and heart rate; large decreases in cutaneous blood flow over the whole body, large increases in blood flow to brown fat depots (in newborn lambs); and a general decrease in blood flow to visceral organs.

Peripheral vasoconstriction is widely regarded as being an "all-or-none" phenomenon which is activated prior to the onset of cold-induced thermogenesis in environments just cooler than the lower critical temperature (Alexander, 1961, 1962 a). However, Webster and Johnson (1968) reported that cold-stressed sheep may

show increased respiration rates (presumably associated with increased thermogenesis) before vasoconstriction has been fully employed. Open faced sheep have been shown to be more productive than sheep with woolly faces, especially in characters concerned with growth and reproduction (Cockrem and Rae, 1966). These differences may be associated with poorer ability of woolly-faced sheep to control peripheral blood flow and therefore body temperature (Cockrem, 1967). Cockrem and Rae (1966) also found that the mortality of lambs born to open-faced ewes was lower than among the progeny of woolly-faced ewes.

In a study with Romney and Drysdale-cross lambs, McCutcheon et al. (1983 a) showed that wetness and air-speed were major determinants of variation in hind-limb skin temperature. Whereas wet lambs were able to minimize the skin temperature - air temperature gradient, dry Romney-type lambs generally failed to do so. As a result their skin temperatures were higher than those of Merino lambs examined under the same conditions (McCutcheon et al., 1983 a). This suggests that an effect of breed type was partially involved (ie. that the ability to reduce vasoconstriction in response to cold may have a genetic basis).

5.3 Surface area to volume considerations

As mentioned before, the maximum heat production of a lamb depends on a number of variables, but particularly on birth weight. As shown by Alexander (1985) summit metabolism (per kilogramm body weight) tends to be constant over a wide range of birth weights. Total summit heat production is therefore directly related to birth weight. However, surface area, which determines total heat loss, is proportional to metabolic body weight (ie.body weight raised to a power of about 0.75). It follows that summit metabolism per unit of surface area is lower in small than in large lambs. This explains the extreme susceptibility of small lambs to inclement weather.

6. Purpose and scope of the investigation

The New Zealand goat industry is expanding and neonatal kid deaths have been identified as a major problem, but little is known about their causes. By contrast, the causes of lamb losses have been well studied. One third of all lamb deaths are due to dystocia (in particular large and/or single lambs are affected) and one third can be attributed to the starvation-exposure-classification (especially small and/or twin lambs). Starvation-exposure deaths, in the absence of poor maternal behaviour, are primarily a result of the inability of some lambs to maintain their deep body temperature in a cold environment. This may in turn reflect a poor ability to achieve and maintain a high summit metabolic rate and limited body insulation (via the birth coat and through control of peripheral vasoconstriction).

Given the higher litter sizes and low birth weights of goats, it is likely that starvation-exposure is a major contributor to neonatal mortality in this species. The objective of this study was therefore to compare responses to cold in newborn lambs and kids with a view to determining similarities and differences in factors affecting their ability to maintain deep body temperature. The study was concerned primarily with the effects of metabolic rate, birth coat characters and body size as determinants of resistance to hypothermia in the two species.

C H A P T E R   II

EXPERIMENTAL

C H A P T E R II

EXPERIMENTAL

COMPARATIVE ASPECTS OF RESISTANCE TO BODY-COOLING IN NEWBORN LAMBS AND KIDS

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ABSTRACT

The aim of this study was to compare responses to cold-stress in newborn lambs and kids. Two experiments, involving 55 lambs and 42 kids, were conducted in a climate chamber with controlled air temperatures and artificial wind and rain. Rectal temperatures were measured and the rate of decline in rectal temperature (RDRT) estimated in both experiments. In the second experiment, metabolic rate was also measured and coat characters (birth coat depth and wool weight per unit area of skin) were examined. The effects of birth rank and sex on resistance to cold exposure and their interaction with species were examined in both experiments.

In Experiment 1 kids had lower rectal temperatures than lambs at the start of the test but there was no species effect on the rate of decline in rectal temperature (RDRT). In Experiment 2, kids exhibited a significantly greater RDRT. Additionally, metabolic rate per unit of live weight was significantly lower in kids and did not increase in response to cold in this species. No differences were apparent between the species in coat characters.

Multiples were found to exhibit a significantly greater RDRT than singles, which was clearly associated with their lower birth weights. Only marginal differences in heat production were observed between the birth ranks. No significant effects of sex on resistance to cold-stress were found in this study.

It is concluded that a combination of low heat production capacity and small body size is responsible for the poor responses of newborn kids to cold-stress but there is probably little difference between lambs and kids in the insulative value of their birth coats.

INTRODUCTION

In recent years, there has been increasing interest in farming of goats for fibre production. These goats are commonly kept under grazing conditions which are associated with low management-intensity. Under these circumstances kid losses are reported to be high (van der Westhuysen, Wentzel and Grobler, 1985), but little is known about the causes of this mortality. By contrast the causes of lamb losses have been thoroughly researched. One third of all lamb deaths can be attributed to starvation and exposure, especially in small and/or twin lambs (Hight and Jury, 1970). Failure of the lamb to maintain normal deep-body temperature in a cold environment is associated with many starvation-exposure mortalities (McCutcheon, Holmes and McDonald, 1981). This reflects a poor ability of some individuals to achieve and maintain a high summit metabolic rate, limited body insulation and the effects of small body size.

Given the high litter sizes and low birth weights of goats (Mohrand-Fehr, 1987) it is likely that starvation and exposure is a major contributor to neonatal mortality in this species. The objective of this study was therefore to compare responses to cold in newborn lambs and kids with a view to determining similarities and differences in factors affecting their ability to maintain deep-body temperature. Two experiments were conducted to examine the effects of metabolic rate, birth coat characters and body size on resistance to hypothermia in the two species.

MATERIALS AND METHODS

Climate chamber

      The lambs and kids were tested in a climate chamber measuring 1.24m long x 0.51m wide x 0.63m high (Figures 1 and 2). The chamber was constructed of hardboard on a steel frame and its floor, ceiling and walls were lined with 30 mm expanded polystyrene. The front of the chamber was fitted with a clear perspex window which allowed the animal's head to be observed from outside the chamber.

      The animal was held within the chamber in a cage constructed of steel mesh, in a standing position, on an adjustable floor. It was prevented from moving by 6 mm diameter plastic-covered steel bars passed through the mesh in front, behind, across the back and underneath the animal. A sliding perspex door was built into the side of the chamber. This allowed observation of the animal, adjustment of equipment and taking of rectal temperatures with minimum interference to temperature control.

      The climate chamber was located in an insulated room, the temperature of which was maintained by mechanical refrigeration. Mean air temperatures were 8.8 (s.e. 0.6) °C during Experiment 1 and 5.7 (s.e. 0.1) °C during Experiment 2. Airspeed was provided by a 315 mm diameter electric fan [General Electric Company (NZ) Ltd, Wellington] located towards the rear of the climate chamber and maintained at a constant setting. Airspeed was measured using a

35

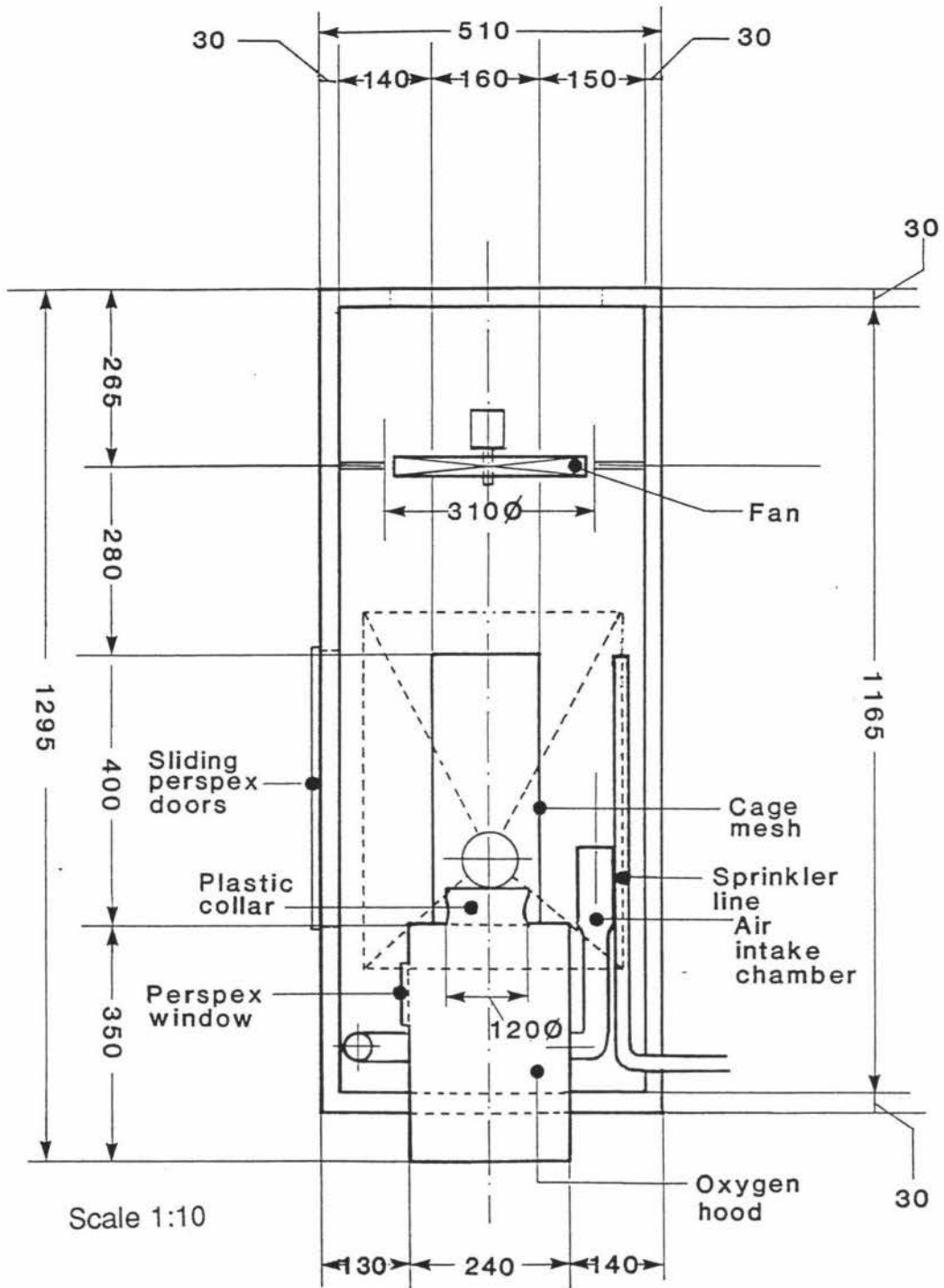Figure 1: PLAN VIEW OF CLIMATE CHAMBER

620

30

560

30

Scale 1:10

fan

sprinkler line

P   Plastic collar

I   Air intake

I

P

air exhaust pipe

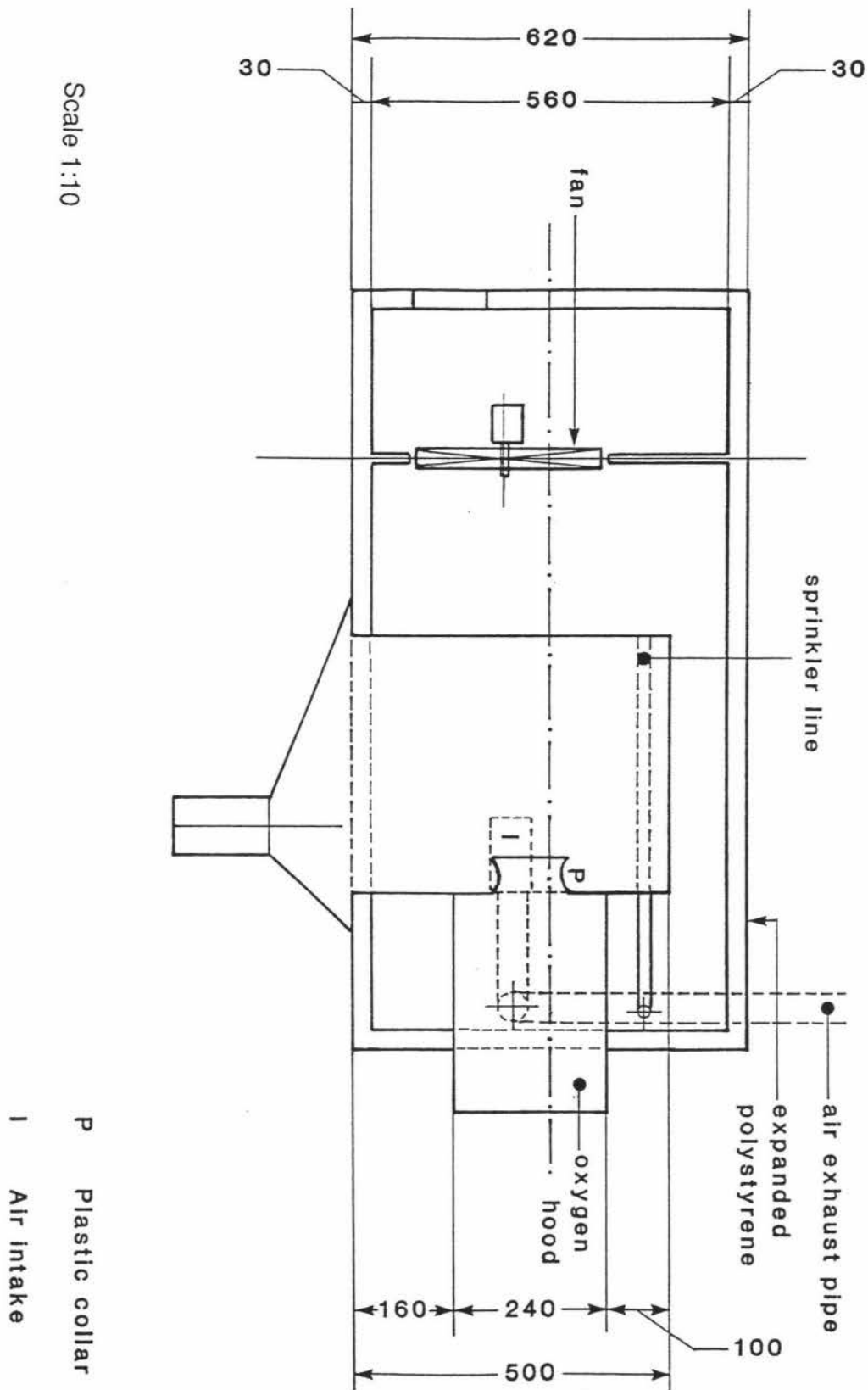expanded
polystyrene

oxygen
hood

←160→←240→

←100

500

FIGURE 2: SIDE ELEVATION OF CLIMATE CHAMBER

standard unsilvered kata thermometer (C.F.Casella and Co.Ltd, London). The mean rate of air movement was estimated to be 1.93 (s.e. 0.08) m/sec for Experiment 1 and 1.74 (s.e. 0.03) m/sec for Experiment 2, from 6 observations within the chamber (100 mm from back of cage, 270 mm from floor to bottom of bulb).

Wetness of the animal was maintained by an overhead sprinkler line placed in the top of the chamber and sprinkling directly onto the animal. Water flow was maintained at a rate of 26 $l.hour^{-1}$, which was more than sufficient to saturate the animal's coat.

The climate chamber was modified for Experiment 2 to allow measurement of oxygen consumption via a ventilated hood in an open-circuit system similar to that described by Holmes (1971). The hood, of metal construction, was mounted in the front of the climate chamber and was fitted with a clear perspex window which allowed the animal's head to be observed from outside the chamber. A plastic collar fitted into the hood was fastened around the animal's neck to seal the hood during the test period.

Air was drawn into the hood through a 25 mm poly vinyl-chloride (PVC) pipe in the lower front corner of the hood at a rate of 16.1 $l.min^{-1}$ which ensured that the oxygen content of the exhaust air did not fall below 19%. The "Air-Intake-Pipe" was connected to a two-litre "Air Intake Chamber" which buffered the system against movement of expired air out of the hood and which drew air from within the climate chamber.

Air was drawn out of the hood through an "Air-Exhaust-Pipe" to the gas meters and oxygen analyser. The exhaust air was cooled to 5°C and then rewarmed to 23°C before passing through the gas meters.

The direct measurements made were ventilation rate and the composition of inlet and outlet air. These values were used to calculate the quantities of oxygen consumed and thus the animal's heat production. Total gas flow rates were calculated separately for each animal test and volumes were corrected to standard temperature and pressure (STP). The oxygen concentration of small dried samples of the ingoing and exhaust air was measured by a paramagnetic analyser (Model OA 137, Servomex and Company, England) with a range of 19% to 21% oxygen concentration. The output of the analyser was connected to a potentiometric chart recorder (J.J.Co. Ltd, United Kingdom) and the oxygen concentration in the inlet and exhaust gases was read from the recorder chart. The rate of oxygen consumption was calculated as the product of the ventilation rate (corrected to STP) and the difference in percentage oxygen concentration between the ingoing and exhaust air samples.The oxygen analyser and chart recorder were calibrated daily against gases of known oxygen concentration. Rate of heat production was calculated from oxygen consumption by the formula of McLean (1972) and was expressed in Watts per kilogram of liveweight $(W.kg^{-1})$.

<u>Animals</u>

Experiment 1 involved twenty-five Poll Dorset x (Border Leicester x Romney) lambs and sixteen Angora x Feral kids while in Experiment 2 thirty Suffolk x (Border Leicester x Romney) lambs and twenty-six Angora x Feral kids were used. The dams of these animals were transported to the Animal Physiology Unit at least one week prior to parturition. There they were housed in individual pens and offered a diet of mixed pasture and pasture hay. Water was available <u>ad libitum</u>.

Ewes and does were observed between 0800 h and 2300 h for signs of impending parturition and, when considered necessary, assistance was given at birth. As soon as possible post-partum each lamb or kid was tagged and its birth weight, birth rank, sex, date and estimated time of birth, eartag number and dam number were recorded. If parturition had occurred between 2300 and 0800h, and had therefore not been observed directly, the time of birth was estimated to the nearest hour from the degree of wetness of the birth coat and from progress of the newborn towards standing and suckling. The animals were tested at varying ages ranging from 0.5 - 21 hours post-partum for Experiment 1 and 0.5 to 30 hours post-partum for Experiment 2.
Animals born during the day were tested as soon as possible, whereas those born during the night or late in the evening were tested the next day.

Experimental procedure

Experiment 1. Immediately prior to testing the animals, the live weights and ages at test were recorded. The animals were injected with Terramycin (Pfizer Laboratories, Wiri, Auckland) at a dose rate of 1 ml/10 kg body weight to prevent any risk of infection occurring during or after testing.

The lambs and kids were then immersed in a waterbath (approximately 20°C) in order to achieve a wet birth coat. Water was rubbed well into the coat and the animals were then allowed to stand in a warm room for several minutes until excess water had drained from the coat. Following this they were placed in the climate chamber and firmly secured with the steel bars to prevent any movement or injury.

Rectal temperatures were measured to 0.1°C with prismatic-type clinical thermometers ("Phoenix",Japan) inserted 6 cm into the rectum for a period of one minute. A "zero-time rectal temperature" (RT0) was taken after securing the animal in the chamber immediately before its exposure to artificial rain and wind. Further readings of rectal temperatures were recorded every 10 minutes. Animals were tested for 120 minutes or until their body temperatures dropped to 35°C. After testing they were dried and then rewarmed in an incubator until their body temperatures reached 39°C or above. The umbilical cord was sprayed with antiseptic solution (Biocil- Ethical Agents Ltd, Auckland)and the lambs or kids were then returned to their dams and mothered up where necessary.

Experiment 2. This was generally as described for Experiment 1, but an "Initial Rectal Temperature" was taken before wetting of the animals (i.e. immediately after separation from the dam). Following this the animals were wetted and secured in the now modified climate chamber as described for Experiment 1. The animal's head was passed through the plastic collar into the hood. The plastic collar was then fastened around the animal's neck to seal the hood during the test period.

As in Experiment 1, rectal temperatures and chamber temperatures were measured every ten minutes for 120 minutes or until the animal's rectal temperature reached 35°C. Heat production measurements were made, also every ten minutes, through indirect calorimetry in the open-circuit system.

Birth coat depth was measured with a pair of modified dial calipers (Mitutoyo Co., Japan) at the midside position over the last rib. Depth measurements were made in duplicate after the animals had been immersed in the waterbath.

The weight of wool per unit area of skin was assessed by clipping the wool from a measured area of skin on the midside, immediately anterior to the last rib. Samples were taken from the animals on the day following exposure in the climate chamber in order to allow the coat to dry. Wool was clipped to within 1 mm of the skin surface and the area of skin clipped, approximately 4 cm wide and 5 cm long, was measured to 1 mm with the dial calipers after the skin had been stretched just sufficiently to remove any

wrinkles.

The midside wool samples were stored in labelled air-tight
plastic bags and, at the completion of the trial, were allowed to
come to equilibrium with a controlled environment of 68% relative
humidity (i.e. regained) over a period of several weeks. They were
then weighed to the nearest 10 mg and the weights expressed as mg
(greasy) wool per cm2 skin area.

Blood sampling and analysis

During Experiment 1, blood-samples were taken to measure
possible differences in blood concentrations of Triiodothyronine
(T_3) and Thyroxine (T_4) between the two species.

Seven animals of each species were used and 3 samples per
animal taken at varying intervals. Wool was clipped over the jugular
vein and approximately 2 ml of blood was collected by venipuncture
into heparinised vacutainers (Terumo Corporation, Tokyo, Japan). The
blood samples were immediately centrifuged (2500g, 4°C) and the
plasma was then harvested and frozen in duplicate vials at -12°C
until subsequent analysis.

T_3 and T_4 concentrations were determined using Coat-A-Count
Total T3 and Total T4 radioimmunoassay kits (Diagnostic Products
Corporation, Los Angeles, CA, USA). The assays were validated for

T_3 and T_4 analysis in ovine and caprine plasma using pooled plasma samples from the animals in this study. Both lamb and kid samples displaced labelled T_3 and T_4 in parallel with the standard curve (Appendix 1) and internal recoveries of added standards were 91-100 % and 84-104 % respectively. The intra-assay coefficient of variation averaged

5.7 % and 7.5 % (40 determinations each) and all samples from the experiment were run in one assay.

Statistical analysis

Data relating to variables measured on only one occasion (e.g. body weight, initial and zero-time rectal temperatures, coat characteristics) were subjected to analysis of variance to test the effects of species, rank, sex and their first order interactions. Analysis of variables measured on multiple occasions (rectal temperature, heat production) was complicated by the fact that animals were removed from the test once their rectal temperatures reached 35°C. Thus the number of animals remaining on test declined as the test proceeded. Accordingly, proportions of animals remaining on test are presented graphically (without analysis) and analysis was restricted to measurements made during the first 20 minutes (the period during which all animals remained on test during each experiment). These data were subjected to multivariate (repeated measures) analysis of variance to test the influence of main effects

(species, rank, sex), their first order interactions, and their interactions with time of measurement. Where appropriate, effects of species, rank and sex additional to those mediated via the associated differences in body weight were tested by fitting body weight first in the model. All analyses were undertaken using the 'REG' computer package (Gilmour, 1985).

RESULTS

Experiment 1

Figure 3 shows the proportion of animals remaining in the study at each measurement time (i.e. those whose rectal temperatures had not reached 35°C at the previous time). Initially, no differences between the species were found. However by 40 minutes there was a considerable difference with 85% of the lambs, but only 50% of the kids, remaining on test. Thereafter the proportion of animals in the two species remaining in the test declined in parallel.

Differences between the ranks were found, 90% of the singles and 65% of the multiples remaining on test at 40 minutes. At subsequent times the proportion of animals in the two ranks remaining on test continued to diverge so that, at 120 minutes, 70% of the singles and and only 29% of the multiples remained on test. No apparent differences between male and female animals were found.

Because animals were progressively removed from the test, comparisons of rectal temperatures and the rate of decline in rectal temperature were made only over the first 20 minutes, the period during which all animals remained in the study.
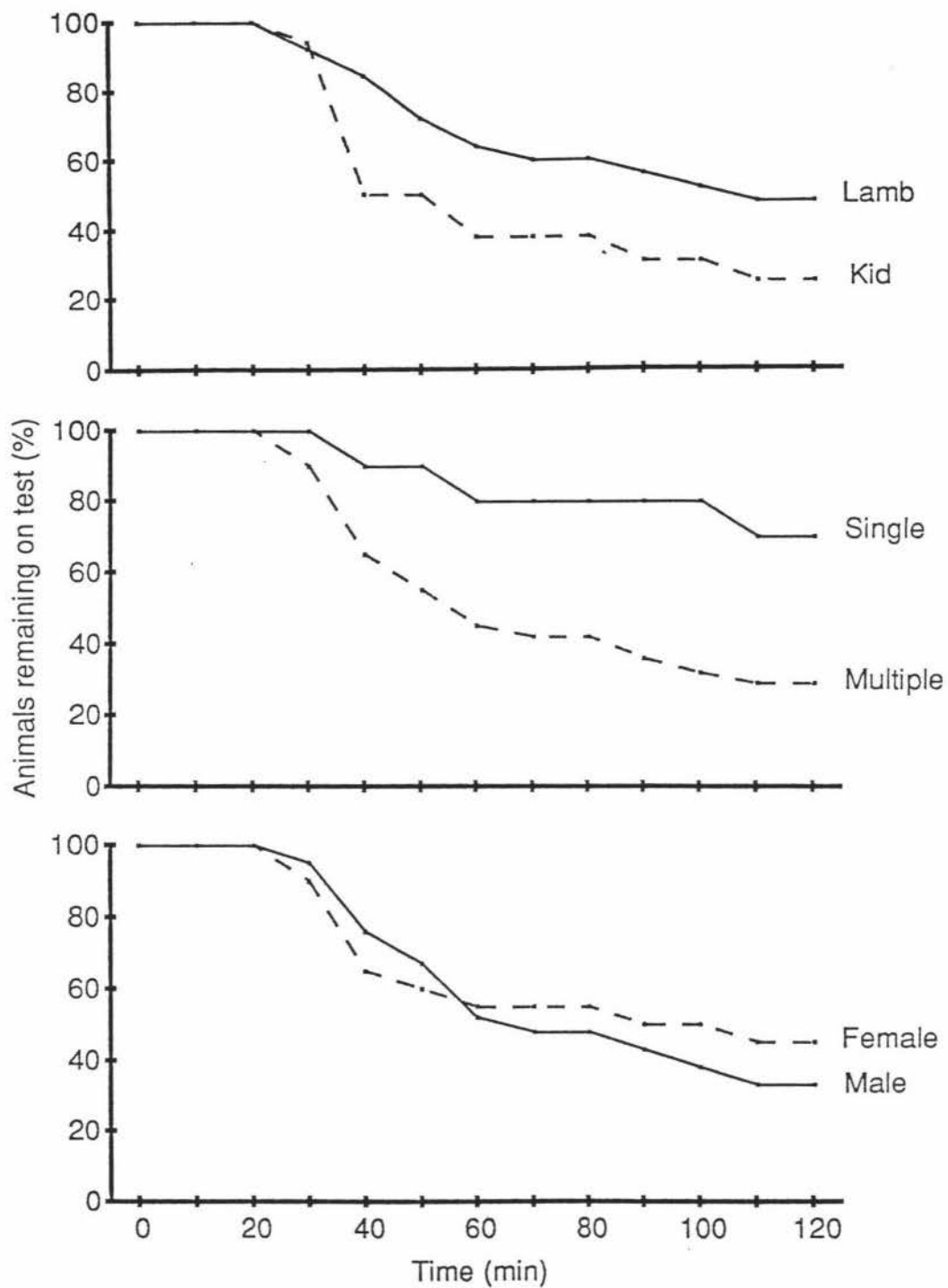
Figure 3: Percentage of animals remaining on test with a rectal temperature above 35°C, by species, rank and sex during Experiment 1.

The pattern of change in rectal temperatures is shown in Figure 4. There was a significant (P<0.01) difference between the species in rectal temperature with lambs showing higher rectal temperatures than kids. The species x time interaction was not significant. Thus the greater rectal temperatures of lambs during the first 20 minutes reflected the fact that they had higher rectal temperatures at time zero ("RT0", P<0.001, Table 1) but no difference in rate of decline in rectal temperature ("RDRT", Table 1).

Whereas the greater live weight of lambs (compared with kids) was associated with a higher RT0 but no difference in RDRT, a different pattern was evident in the comparison of the birth ranks. As expected, singles were heavier than multiples (P<0.05, Table 1). However, while RT0 was not influenced by rank, multiples exhibited a much greater RDRT than singles (P<0.01, Table 1). Males were also heavier than females but this weight difference was not associated with differences either in the RT0 or in the RDRT during the first 20 minutes on test (Figure 4 and Table 1).

There was a significant species x sex interaction in RT0 (P<0.05, Table 1). Whereas in the lambs, females showed a higher RT0 than males by 0.5°C, the reverse was true in the kids. No other interactions between the main effects were significant.

Live weight was positively related to RT0 (P<0.001) and correction of rectal temperatures at commencement of the test to a common live weight eliminated the significant effects of species.
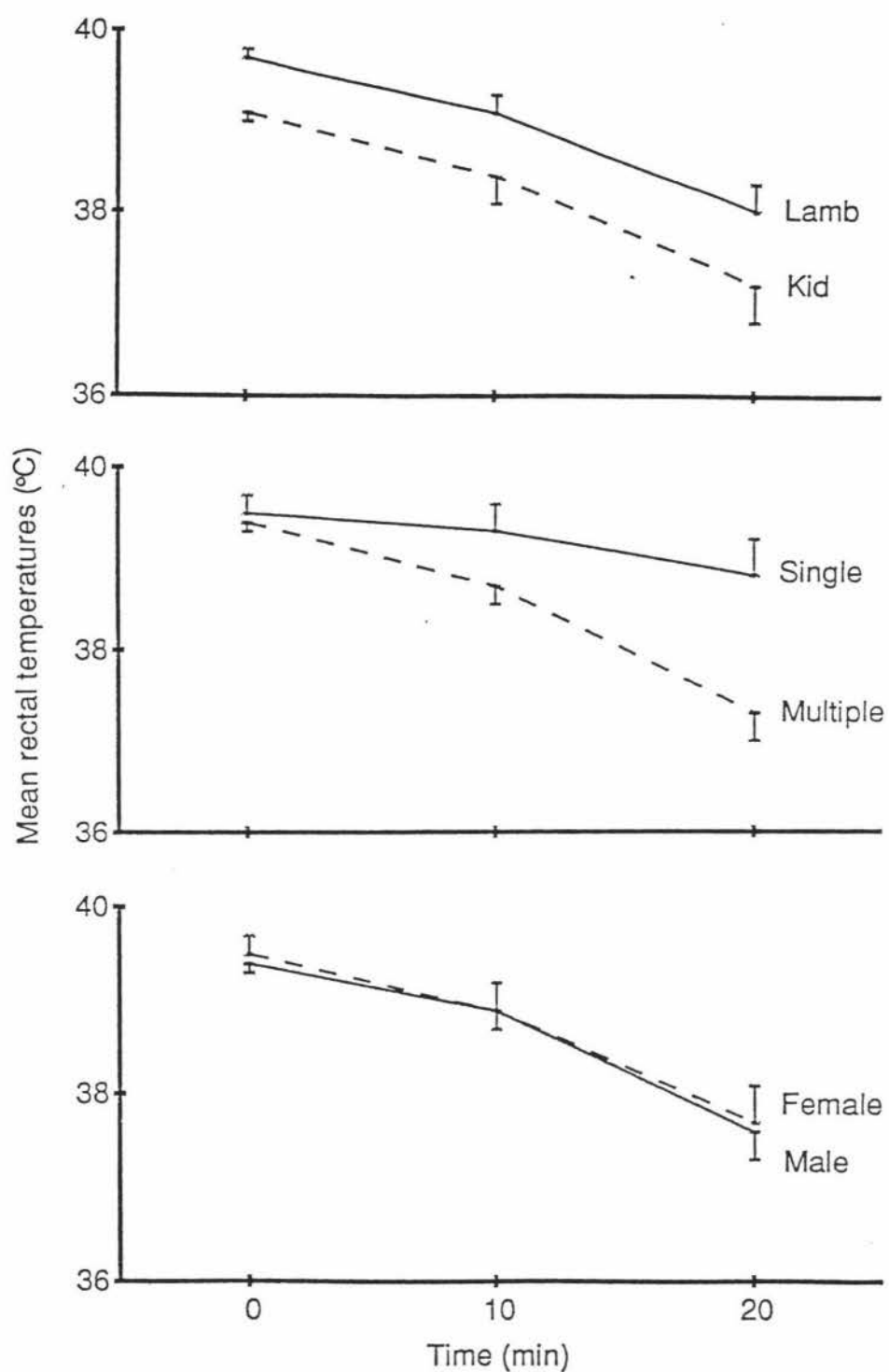
Figure 4: Change in mean rectal temperatures (°C) over the first 20 minutes on test, by species, rank and sex during Experiment 1.
Vertical bars denote the standard error.

However, when compared at a common live weight, RDRT during the first 20 minutes was influenced both by species and by birth rank (P<0.05; lambs 0.098 $\pm$0.018 °C/min; kids 0.038 $\pm$0.021°C/min; singles 0.043 $\pm$0.018°C/min; multiples 0.093 $\pm$0.012°C/min). Thus when compared at a common live weight lambs were more susceptible to cold-stress than kids, and birth rank exerted effects on RDRT additional to those mediated through live weight.

No effect of species on plasma T_3 and T_4 levels (pooled across blood collection times) was observed in this study (plasma T_3: lambs 350.18 $\pm$30.42 ng/dl, kids 332.73 $\pm$30.42 ng/dl; plasma T_4: lambs 13.20 $\pm$0.97 ng/dl, kids 13.49 $\pm$0.97 ng/dl).

Experiment 2

Figure 5 shows the proportion of animals remaining in the study at each sampling time. As in Experiment 1, no differences between the species were found during the first 30 minutes of the test. Thereafter, the proportion of animals in the two species remaining on test diverged rapidly, so that at 120 minutes, 77% of the lambs but only 23% of the kids remained in the test.

Comparison between singles and multiples showed few differences during the first 30 minutes on the test. However, at 40 minutes all singles remained on test, whereas 18% of the multiples had already reached a body temperature below 35°C and had been removed from the test. Thereafter the proportion of animals in the
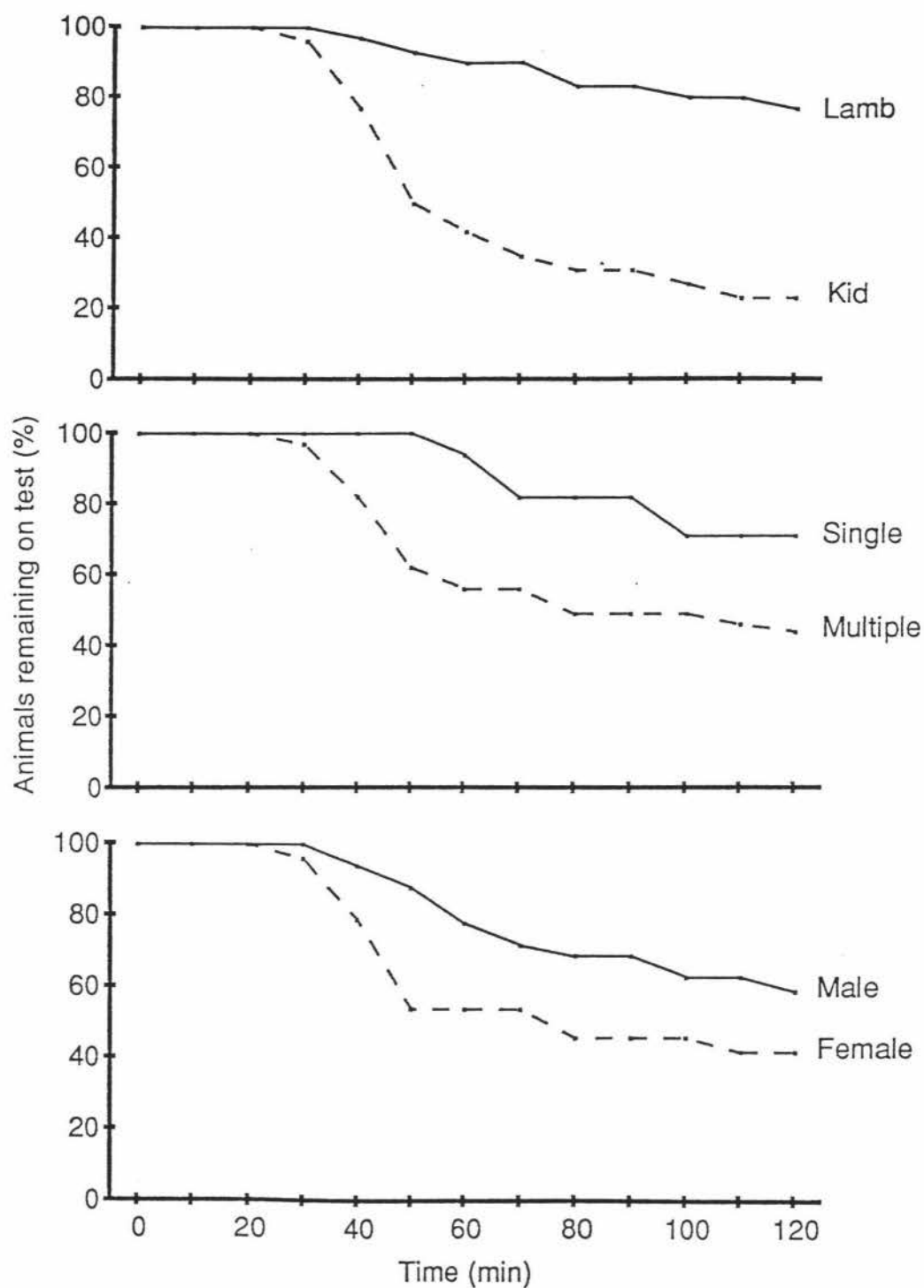
Figure 5: Percentage of animals remaining on test with a rectal
temperature above 35°C, by species, rank and sex
during Experiment 2.

TABLE 1

Effects of species, rank and sex on live weight (WT), rectal temperature at commencement of test (RT0) and rate of decline in rectal temperature (RDRT) during the first 20 minutes on test. (mean $\pm$ se)

	n	WT (kg)	RT0 (°C)	RDRT (°C/min)
Species				
Lamb	25	4.23 ±0.13	39.75 ±0.12	0.072 ±0.013
Kid	16	2.51 ±0.15***	39.08 ±0.14***	0.068 ±0.016
Rank				
Single	10	3.62 ±0.18	39.45 ±0.17	0.038 ±0.019
Multiple	31	3.12 ±0.11*	39.38 ±0.10	0.103 ±0.011*
Sex				
Male	21	3.60 ±0.14	39.37 ±0.13	0.075 ±0.014
Female	20	3.15 ±0.14*	39.46 ±0.13	0.066 ±0.014

Species	Sex	n	RT0 (°C)
Lamb	Male	13	39.50 ±0.15
	Female	12	39.94 ±0.15
Kid	Male	8	39.27 ±0.18
	Female	8	38.83 ±0.19

two birth ranks remaining on test declined almost in parallel. Some differences in the proportion of male and female animals remaining on test were observed (in favour of the males).

Comparisons of rectal temperatures, RDRT and heat production were again made only over the first 20 minutes, the period in which all animals remained in the study.

Figure 6 shows the rectal temperatures of animals during the first 20 minutes on test. Initial rectal temperature (i.e. that measured prior to immersion in the waterbath) was not significally influenced by species (Table 2), but was marginally higher in the kids. However, the first rectal temperature measured in the chamber (RT0) was significantly (P<0.01) lower in kids than in lambs. Thereafter, rectal temperatures in the two species continued to diverge (Figure 5), the RDRT being significantly (P<0.01) greater in kids than in lambs (Table 2). As in Experiment 1, kids were lighter than lambs (P<0.001, Table 2).
When comparisons were made at an equal live weight, no differences were apparent between the species in RT0 or RDRT.

Comparisons of the birth ranks showed no influence of rank on IRT (Table 2), but RT0 was significantly (P<0.01) higher in singles. Differences between the ranks in RDRT were significant (P<0.01, Table 2), with the significantly (P<0.001) lighter multiples exhibiting a greater RDRT.
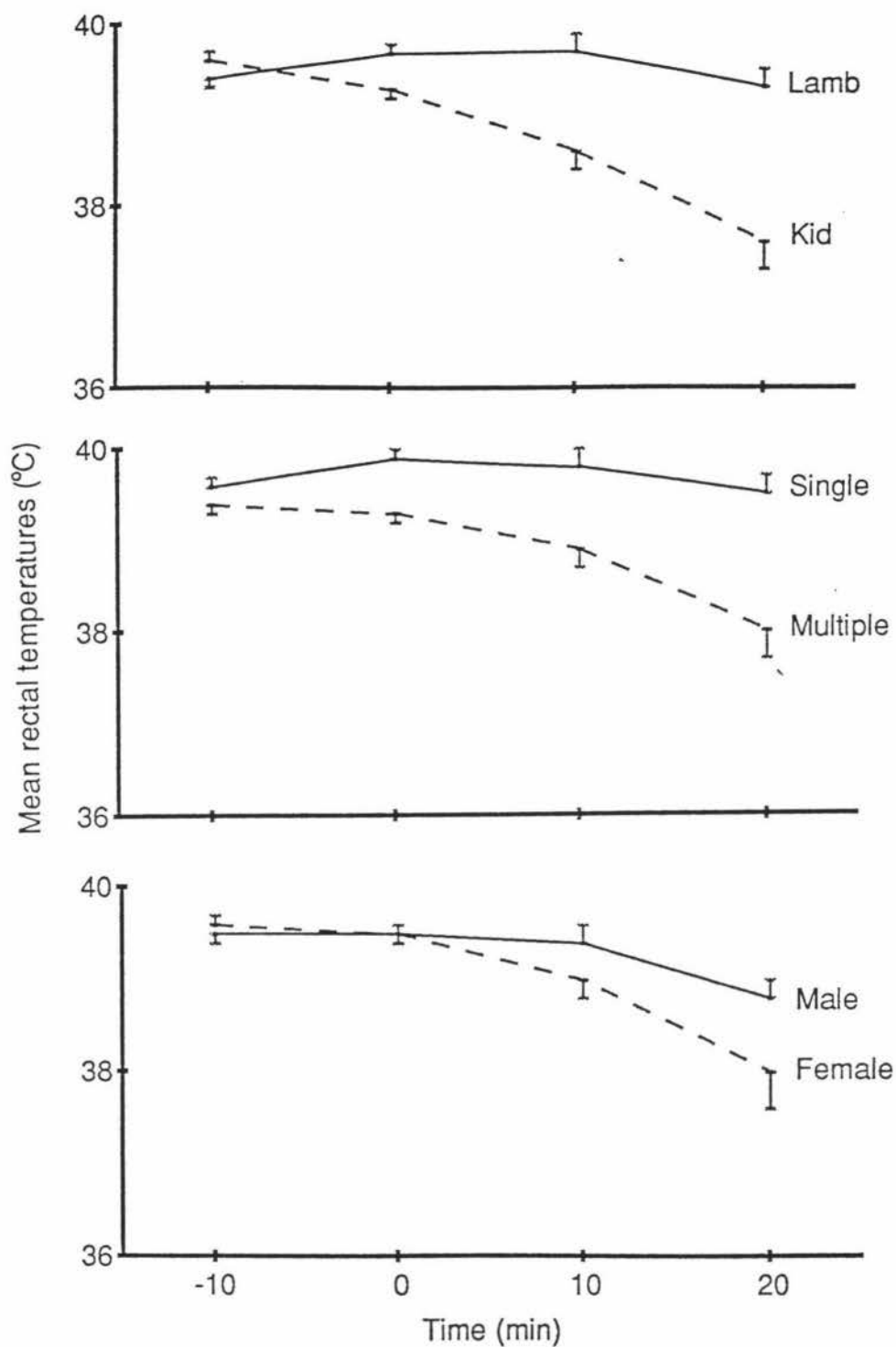
Figure 6: Change in mean rectal temperatures (°C) over the first
20 minutes on test, by species, rank and sex
during Experiment 2.
(Reading at -10 = IRT)
Vertical bars denote the standard error.

TABLE 2

Effects of species, rank and sex on live weight (WT), initial rectal temperature (IRT) and rate of decline in rectal temperature (RDRT) (mean $\pm$ se).

	n	WT (kg)	IRT (°C)	RDRT (°C/min)
Species				
Lamb	30	4.32 $\pm$0.10	39.47 $\pm$0.10	0.023 $\pm$0.009
Kid	26	2.30 $\pm$0.12***	39.58 $\pm$0.13	0.065 $\pm$0.011***
Rank				
Single	17	3.66 $\pm$0.14	39.58 $\pm$0.14	0.022 $\pm$0.013
Multiple	39	2.96 $\pm$0.08***	39.46 $\pm$0.09	0.066 $\pm$0.008**
Sex				
Male	32	3.50 $\pm$0.09	39.54 $\pm$0.09	0.042 $\pm$0.008
Female	24	3.18 $\pm$0.13	39.51 $\pm$0.13	0.046 $\pm$0.019

Males were heavier than females (Table 2) and this weight difference was associated with a difference in RDRT (Table 2), females having a greater (P<0.10) RDRT than males. As expected, correction to a common live weight eliminated the significant effects of both sex and rank on RDRT.

Heat production (per unit liveweight) during the first 20 minutes on test is shown in Figure 7. Differences in heat production between the species were highly significant ($P < 0.001$), with kids exhibiting a lower level of heat production than lambs. Heat production at the start of the test was found to be significantly ($P < 0.001$) lower in kids than in lambs. This difference increased during the remainder of the test. Whereas lambs increased their heat production steadily over the first 20 minutes of the test, the kids appeared to reach a plateau after 10 minutes and did not increase heat production thereafter. Accordingly the species x time interaction was found to be highly significant ($P < 0.001$).

A marginal difference in heat production between singles and multiples was observed, but was significant only at the 10% level. No effect of sex on level of heat production was apparent.

The depth of the birth coat was found to be significantly ($P < 0.05$) affected by both birth rank and sex of the animals (Table 3). However, no differences between the species in birth coat depth were apparent in this study (Table 3). No significant effects of species, birth rank and sex on wool weight per unit area of skin were found, but a significant ($P < 0.05$) rank x sex interaction was observed (Table 3).
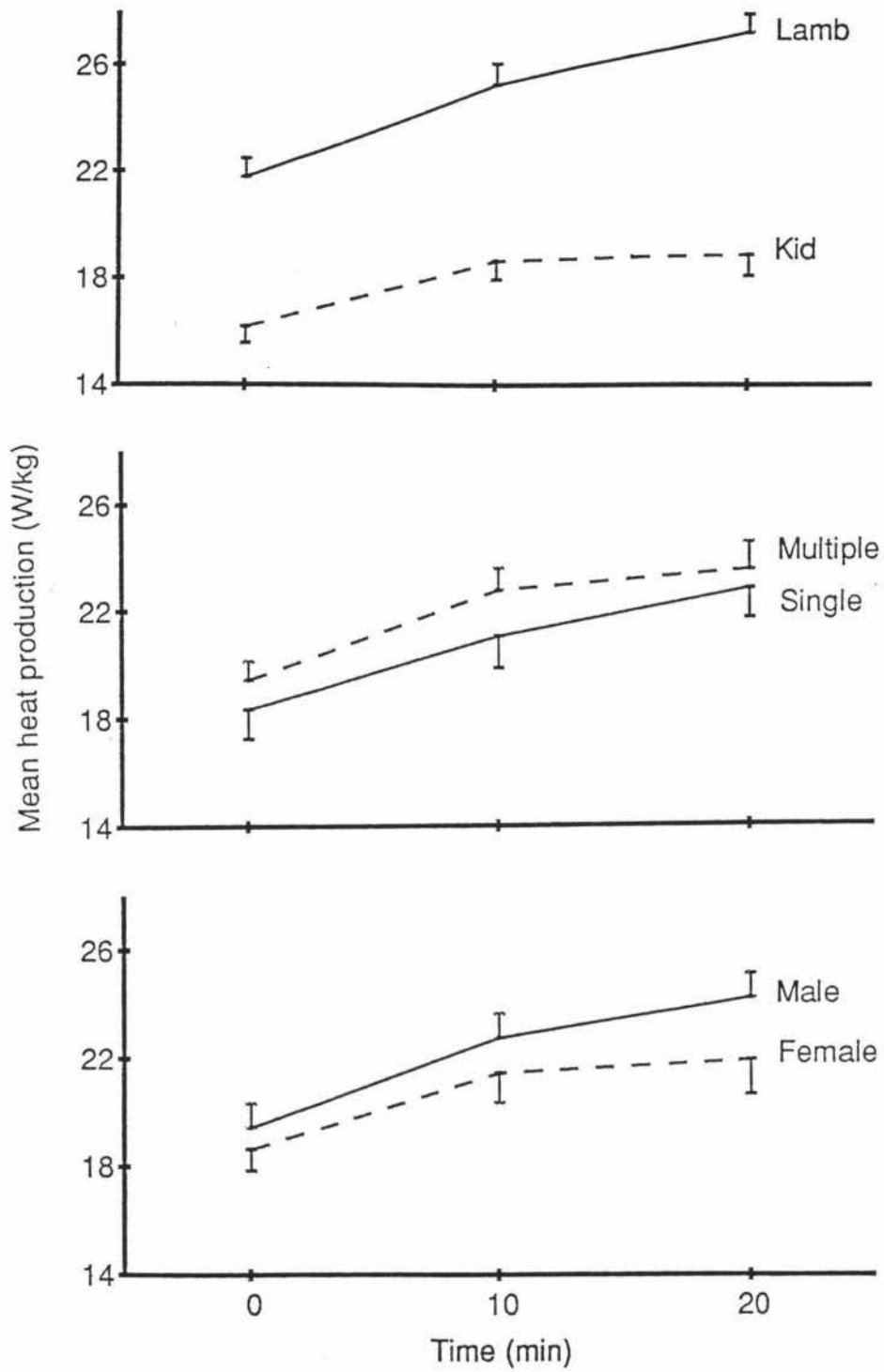
Figure 7: Change in mean heat production (W/kg) over the first
20 minutes on test, by species, rank and sex
during Experiment 2.
Vertical bars denote the standard error.

TABLE 3

Effects of species, rank and sex on coat depth and wool weight
per unit area of skin. (mean ±se).

	n	coat depth(mm)	woolweight (mg/cm^2)
Species			
Lamb	30	5.48 ±0.19	2.60 ±0.09
Kid	26	5.08 ±0.23	2.28 ±0.11
Rank			
Single	17	5.44 ±0.26	2.42 ±0.13
Multiple	39	5.12 ±0.16*	2.46 ±0.08
Sex			
Male	32	5.20 ±0.17	2.43 ±0.09
Female	24	5.36 ±0.25*	2.45 ±0.12

Rank	Sex	n	wool weight (mg/cm^2)
Single	Male	12	2.59 ±0.13
	Female	5	2.25 ±0.23
Multiple	Male	20	2.26 ±0.11
	Female	19	2.65 ±0.11

DISCUSSION

This study used two indices of resistance to cold-stress. In both experiments the rate of decline in rectal temperature (RDRT) was used as the main index of resistance to cold-stress. Additionally, metabolic rate (W/kg) was measured in Experiment 2.

No effects of sex on resistance to cold-stress were found in this study, although males had higher live weights than females while the reverse was true with respect to midside coat depths. This result differs from the findings of McCutcheon et al. (1983) who showed that male lambs exhibited a greater resistance to cold-stress than females and that this was largely attributable to their greater live weights.

Multiple-born lambs and kids were more susceptible to cold-stress than single-born animals. Multiples exhibited a significantly greater RDRT than singles, despite the fact that no differences existed in initial rectal temperature (IRT) or the rectal temperature at the beginning of the test (RT0). Only marginal differences between the ranks were found in heat production. The between-rank differences in RDRT were clearly attributable to the greater live weights of singles. This corresponds with the findings of Dalton et al. (1980), who reported that the reduced survival ability of multiples was almost certainly due to their lower live weights. However, as suggested by Eales et al. (1982), birth rank may also have an effect on resistance to cold-stress independent of birth weight. In this study, comparison at a common live weight did

not eliminate the marginal differences in heat production between the birthranks. In addition, multiples were found to exhibit significantly lower midside coat depths than singles, which corresponds with the results of a study by McCutcheon et al. (1983).

The results of the two experiments show clearly the greater susceptibility of newborn kids to a cold environment compared with lambs. Kids exhibited a marginally higher initial rectal temperature (immediately after removal from the dam) than lambs (Experiment 2). Their ensuing RT0, measured after they had been wetted and placed in the climate chamber, was significantly lower than that of lambs. This initial difference in RT0 was maintained in Experiment 1, with no apparent differences in the RDRT between the species. In Experiment 2, the initial("RT0") difference in rectal temperatures was greater than that in Experiment 1 and kids exhibited a significantly greater RDRT than lambs. Why this difference in species effect on RDRT occurred between the experiments can only be speculated on. Kids in Experiment 2 were lighter than those in Experiment 1, but this is unlikely to have accounted for the difference between the experiments. Differences in live weight between the species were 1.72 kg in Experiment 1 and 2.02 kg in Experiment 2. New Zealand goats, including those used in the study, have a high percentage of feral genes because they have not been farmed for as long as sheep. Therefore, a greater genetic diversity may exist in the goat population. Sampling small numbers of goats for this study may therefore have lead to the variable species effects on RDRT in the two experiments. Nevertheless, although no significant differences in RDRT between the species were found in

Experiment 1, the fact remains that the proportion of animals maintaining their rectal temperatures above 35°C was approximately twice as high in lambs as in kids, primarily because the kids had low rectal temperatures at the start of the test.

Lambs and kids did not differ in midside coat depth or wool weight per unit area of skin and this suggests that only small, if any, differences in coat insulation exist between the species. No differences in thyroid hormone levels (T_3 and T_4) between the species could be detected and it seems unlikely that the poor responses of newborn kids to cold-stress were caused by low thyroid hormone levels. However, the between-species differences in RDRT were clearly attributable to the corresponding differences in birth weight. Kids had a lower heat production per unit live weight than lambs and they did not increase their heat production in response to cold. Although, summit metabolism, as defined by Alexander (1962 b), was not measured directly the results point strongly to the conclusion that newborn kids have a lower summit metabolic rate than lambs.

In conclusion, a combination of low heat production capacity and small body size appears to be responsible for the poor responses of newborn kids to cold-stress. Strategies to improve resistance to cold-stress in newborn kids should therefore include measures to increase their birth weights and elevate summit metabolic rate. In the absence of these changes, which will be difficult to achieve, kids will require higher standards of care in the early postnatal period if they are to achieve the same survival rates as lambs.

C H A P T E R   III

GENERAL DISCUSSION

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The responses of newborn lambs to body cooling have been thoroughly researched and the factors which affect their ability to maintain deep body temperature under adverse climatic conditions are reasonably well known. To our knowledge no such research has been carried out on responses to cold-stress in newborn kids. The main aim of this study was therefore to test the two species under identical conditions to determine differences and similarities in their responses to body cooling. It was hoped that this comparison would allow researchers to apply some of the findings on lambs to the problem of perinatal kid mortality.

Although the comparison of resistance to cold-stress in animals under identical conditions is a commonly used technique in neonatal research (Slee, 1978; McCutcheon, 1981), and is a useful first approach, it does have limitations which must be clearly understood when interpreting the results. Resistance to cold-stress(i.e. the ability to maintain normal deep body temperature in the face of a cold challenge) is determined by many physiological processes including: the level of summit metabolic rate and the speed with which it is attained; insulation provided by the pelage and by the skin through peripheral vasomotor adaptations; behavioural and postural adjustments; and surface area to volume considerations which principally reflect body size. Measurement of

these parameters requires a variety of techniques, not all of which may be accomplished by exposing animals to a constant degree of cold.

The technique for measurement of summit metabolic rate has been described by Alexander (1962 b). This involves measuring the respiratory exchange of lambs during a period of 20 minutes using a climate chamber in which cold air can be blown across the lamb at various speeds. During this period the rate of heat loss is adjusted by means of a variable wind speed, so that the rectal temperature of each lamb falls at a rate of about $1°C$ per 20 minutes. The average metabolic rate achieved during this 20 minute period in which rectal temperature falls satisfactorily is referred to as "summit metabolism". This method has the advantage that the fall in rectal temperature is controlled, and that an extremely low air temperature is not necessary. Because there is wide variation in the response of animals to cold-stress, conditions must be varied to ensure that rectal temperature does not fall uncontrollably during the period that summit metabolic rate is measured. It follows from this that summit metabolic rate cannot be measured when animals are exposed to a constant environment because in some individuals rectal temperature will fall very rapidly while in others it may not fall at all (i.e.summit metabolic rate will not have been attained).

Despite these limitations, some inferences can be made about the relative summit metabolic rates of lambs and kids in the present study (Experiment 2). Whereas the heat production of lambs continued to increase as the test proceeded, that of kids did not and the kids

attained significantly lower levels of heat production than lambs. Associated with this was a greater rate of decline in rectal temperatures, implying that a greater proportion of the kids had attained summit metabolic rate. If this should be so, then the comparison of related species, such as lambs and kids, may be a useful model for studies seeking to examine the physiological basis of genetic differences in summit metabolic rate. However, in Experiment 1 the rate of decline in rectal temperatures was not significantly different between the species, although kids exhibited significantly lower rectal temperatures than lambs at start of test. This lack of difference in the rate of decline in rectal temperature suggests that in Experiment 1 there was no difference between the lambs and kids in the balance between heat production and heat loss, despite the smaller size of the kids. Whether this reflects the fact that kids in that experiment had similar summit metabolic rates to lambs cannot be determined but is a possibility. Thus the results of Experiment 2 may not be applicable to all groups of kids and require confirmation by direct measurement of summit metabolic rate. However, rectal temperature at start of test was different in Experiment 1, as well as in Experiment 2, which could have reflected a slower attainment of summit metabolic rate in the kids in Experiment 1.

Climate chambers such as that employed in this study may also be used to estimate heat loss from animals. Such measurements rely on the assumption that, if rectal temperature is stable, heat loss will equal heat production. Once again the technique is not well suited to a situation in which all animals are exposed to the same

cold environment because, given a range of body weights and summit metabolic rates, some animals will attain summit metabolism, undergo a loss of deep body temperature, and violate the basic assumption of equality between heat production and heat loss. For this reason the present study utilized direct measurement of coat characteristics which are known to influence coat insulation.

The results of Experiment 2 point to the conclusion that there were no differences between the species in midside coat depth and wool weight per unit area of skin. Although this suggests small, if any, differences in coat insulation, the results need to be confirmed and call for a more comprehensive study on coat characters and the direct measurement of heat loss from newborn kids as described previously in lambs by Alexander (1961, 1962 a). In lambs resistance to cold stress was found to be strongly related to coat depth, with twins exhibiting lower midside coat depths by 1.1 mm at each measurement site (McCutcheon et al., 1983). This corresponds with Alexander's (1974 a) report that small lambs tend to have shorter and sparser coats than large lambs. The thermal insulation of the coat of small lambs is therefore low so that per unit of surface area, small lambs tend to exchange heat more rapidly with the environment. Thus it can be inferred that in lambs midside coat depth is positively related to birth weight and negatively to litter size. Although kids were lighter than lambs in the present study, they had comparable birth coat depths and wool weights per unit area of skin. Thus relative to their body size, newborn kids appear to be equipped as well as, or better than, newborn lambs in terms of coat insulation.

The results of this study show clearly that newborn kids are disadvantaged not only by a low metabolic rate per unit of liveweight, but also to a great extent by their low birth weight. Small animals are at a great thermal disadvantage, because heat loss is determined by surface area whereas summit heat production is related to live weight (Alexander, 1962 b). Because small animals have a much higher ratio of surface area to mass than large animals, they must expend more energy per unit of live weight than larger animals to produce heat under cold conditions (Alexander, 1974 a). This seems to be confirmed by the results of the present study. The low live weight of the kids was clearly implicated in the significant differences in RDRT, IRT and RT0 between the two species given that comparisons at equal live weight largely eliminated these differences. However, it is difficult to separate the effects of low body weight _per se_ in the kids from their apparently inferior summit metabolic rate.

Furthermore, small lambs are handicapped by lower energy reserves (fat and glycogen) per unit of live weight than large lambs (Alexander, 1974 a). However, the size of the energy reserves was found to be not obviously related to cold resistance (Alexander and Bell, 1975). Small lambs were found to have relatively less muscle for physical activity and shivering and their spleen, liver, thymus and thyroid weights tended to be disproportionally small (Alexander, 1974 a). Further research is needed to examine these relationships in newborn kids.

The present study has clearly shown that low birth weight is an important factor influencing the cold resistance of newborn kids. It has been shown that birth weight decreases when litter size increases (Mohrand-Fehr, 1987). There are very few opportunities for modifying litter size since prolificacy is a feature of each goat breed population. However, birth weight can be influenced by maternal prenatal nutrition. Results of studies by Everts (1985) in prolific crossbred ewes and by van der Westhuysen (1980) in Angora goats suggest that the birth weight of lambs and kids can be influenced by the feeding of the dam in late pregnancy. However, the results of Robinson and Aitken (1985) suggest that feeding as early as the second and third weeks of pregnancy, through its effect on the early growth and survival of the embryo, can influence size of lambs at birth. Similarly, there is now evidence that extremes of nutrition in mid-pregnancy are detrimental to placental growth (Robinson and Aitken, 1985). Also, the distribution of embryos in the uterus, the number of cotyledons and placental weight can have clear effects on birth weights of lambs, but cannot be readily influenced in the field (Rhind, Robinson and McDonald, 1980). On the other hand in many goat breeds, foetal requirements appear to be strongly supported by nutritional buffering of the dam. Villette-Houssin et al. (1982) showed that in Alpine goats a variation in the level of metabolizable energy intake from 0.7 to 1.5 times maintenance during the last six weeks of pregnancy (lower than maintenance + gestation requirement) had no effect on kid birth weight in the case of single and twin births. In triplet births, however, underfeeding the doe in late pregnancy decreased kid birth weight. Some dairy goat breeds (Alpine and Saanen) appear to have a

higher capacity for energy reserve mobilization than the ewe
(e.g. Ile de France and Limousine) (Mohrand-Fehr, 1987). It cannot
be concluded, however, that underfeeding of the doe in late
pregnancy has little effect on kid losses in the case of breeds
which have a relatively high prolificacy. Certainly energy
limitations for late gestation are not advisable and it is possible
that the situation in goats is similar to that in sheep, i.e. that
birth weight of twins and probably singles decreases with severe
underfeeding of their dams.

Direct selection for higher birth weights is another option to
increase viability in lambs and probably in kids. The magnitude of
the correlation between birth weight and cold resistance was found
to be 0.5 in lambs (Slee, 1985). However, direct selection for
higher birth weights may inadvertently interfere with the selection
for other characters, especially in a relatively young industry,
like the New Zealand goat industry, where intensive selection for
important production traits is being undertaken. Moreover, it was
found that birth weight and littersize are negatively correlated.
Consequently, selection for higher birth weights would not be useful
to reduce losses, because the selection would tend to reduce the
proportion of multiple births (Wassmuth and Jatsch,1980).

Attempts to increase the viability of newborn kids through
selection may be more successful when selecting for other characters
than birth weight _per_ _se_. Direct genetic selection for improved
viability is difficult to envisage since the heritability is low
(Piper, 1982) and high mortality rates would need to be imposed to

achieve sufficient selection intensity for worthwhile progress.

However, indirect selection for a correlated character, such as cold resistance, could be a useful alternative. Recent work (Slee, 1985) reveals within-breed genetic variation for cold resistance with a significant response to selection and an estimated heritability of 30% in lambs. It remains to be seen if cold resistance is subject to similar variation in newborn kids. If so, then genetic improvement has many advantages, because it is permanent. However,it would also be an expensive exercise requiring a high degree of industry organisation to ensure wide use of bucks identified at birth as having superior cold-resistance.

Changes in the resistance to cold-stress are therefore likely to be difficult to achieve in the short-term. Thus, protection from cold and improved post-natal care of kids should be a priority. The provision of shelter is an essential strategy to "warm" the environment effectively by several degrees, under pastoral conditions. In sheep, it has been found that ewes tend to leave the flock for lambing. This may lead ewes to a sheltered site fortuitously, but there is no good evidence that ewes of any breed seek shelter specifically for lambing (Alexander, 1985). Recently-shorn ewes do seek shelter avidly in cold weather, and are therefore likely to lamb there (Lynch et al., 1980). Consequently, unshorn lambing sheep require confinement in shelter, either for the whole of lambing or during periods of high risk. The only shelter extensively studied for lambing sheep has been wind breaks in the form of grass hedges of Phalaris hybrid or fences of"shade"

materials of various porosity (Alexander et al., 1980). The study found that this type of shelter reduced the mortality of single lambs from 17 to 9 % and of twin lambs from 51 to 32 %. However, the most appropriate forms of shelter for goats, and the effects of behaviour of kidding goats on utilization of this shelter require further study.

A P P E N D I X I

Parallelism of ovine and caprine samples in

Triiodothyronine and Thyroxine assays

Pool samples were made up by mixing randomly chosen plasma samples from the lambs and kids used in the study. These pools were then serially diluted with assay buffer (0.5, 1.0, 2.0 and 3.0 dilutions for T_3; 0.5, 1.0, 2.0 and 4.0 dilutions for T_4) and assayed. Appendix Figure 1 shows the assay binding curves and binding of serially diluted plasma samples.

It is clear from these figures that in both assays the lamb and kid plasma samples exhibited displacement of labelled hormone (i.e. tracer) in parallel with the standard curve. This demonstrates that immunoreactivity of the hormones in the plasma samples was essentially the same as that of hormone in the standards.
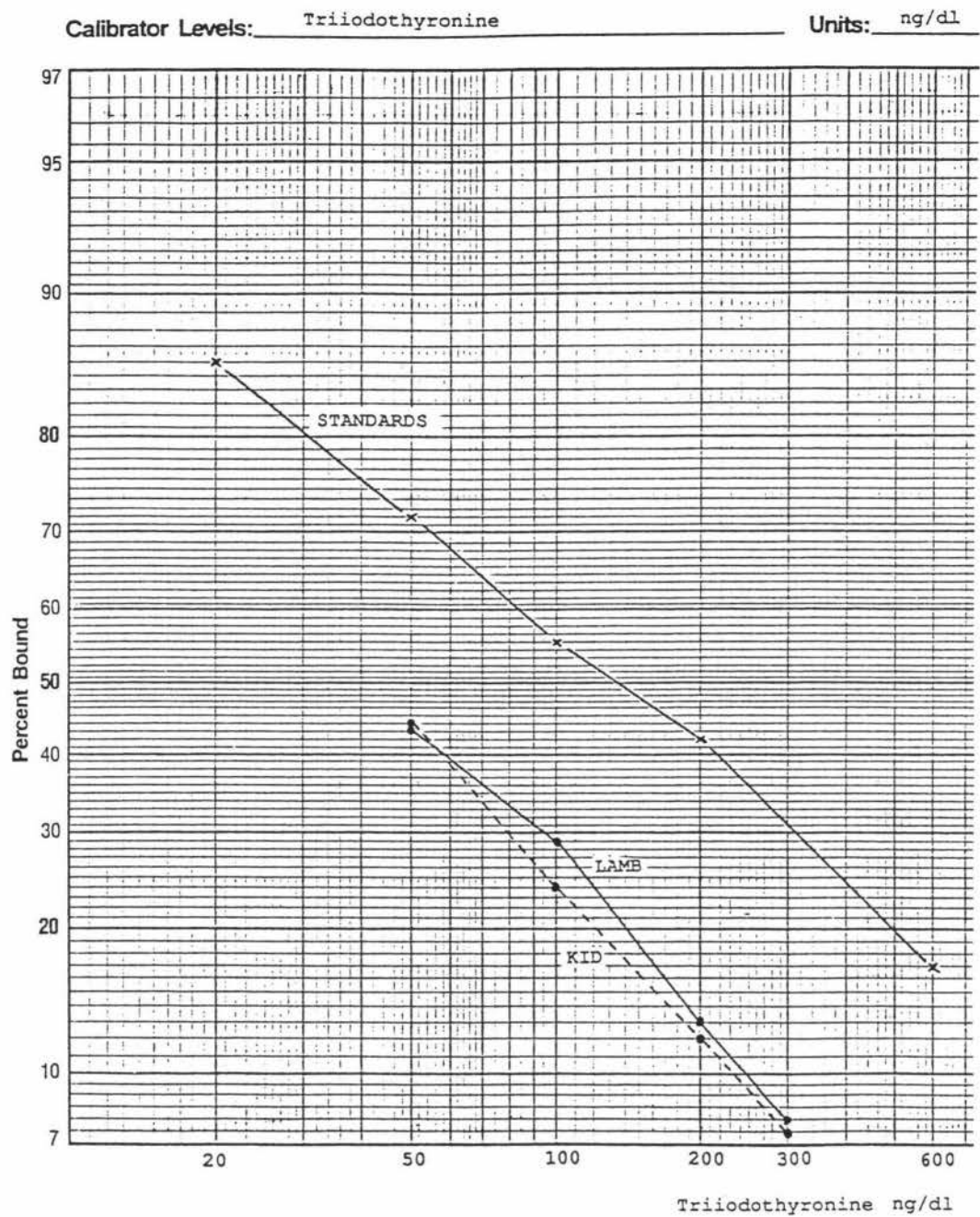
Appendix Figure 1: Binding of standards and of serially diluted ovine and caprine plasma samples in Triiodothyronine (above) and Thyroxine (next page) radioimmunoassays. Details of the assays are provided in the Materials and Methods section (page 42).

Calibrator Levels: <u>Thyroxine</u>   **Units:** <u>ng/dl</u>

Thyroxine ng/dl
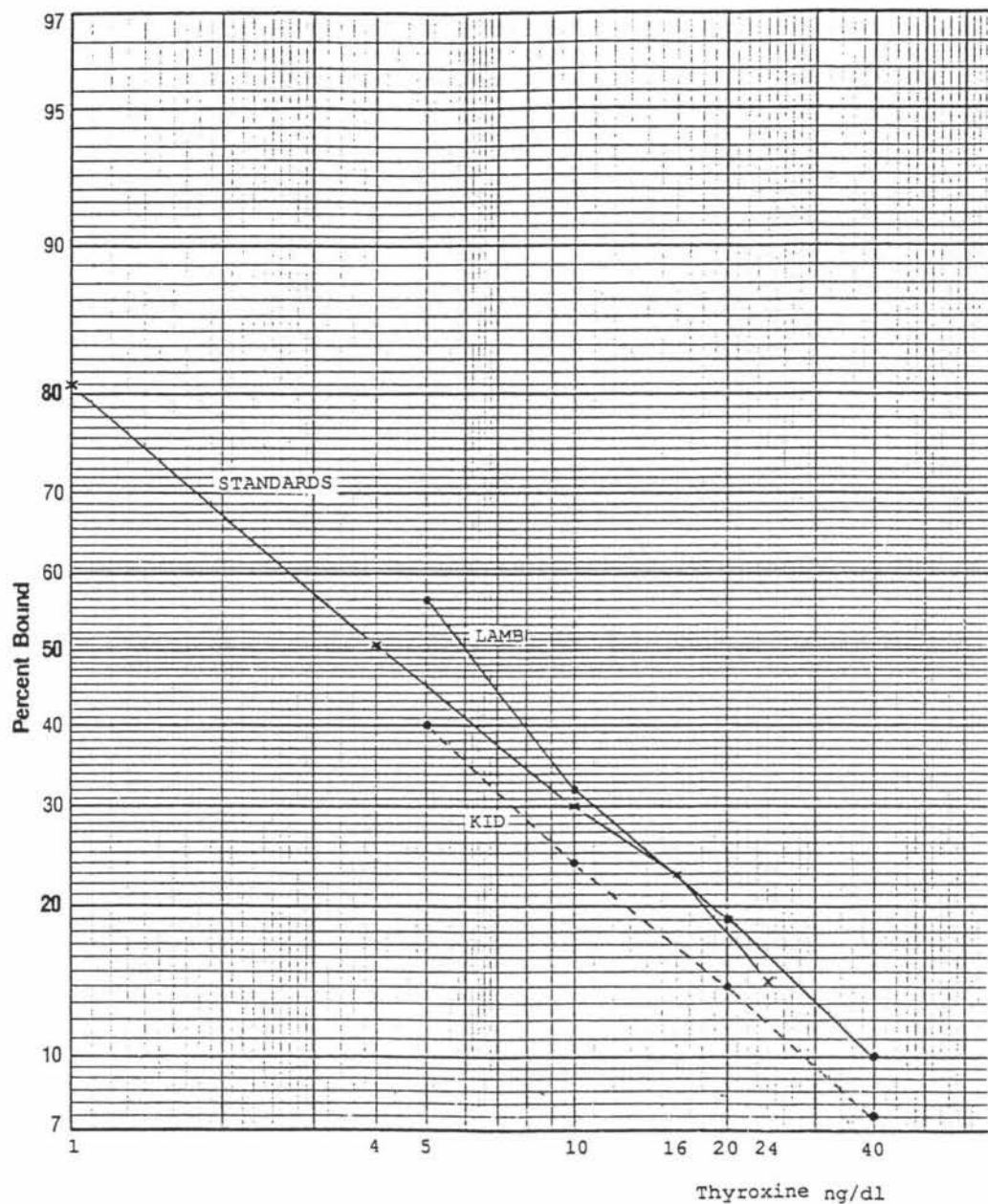
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