TEMPERATURE ADAPTATION IN THE BABY PIG

A THESIS
for the Degree of Master of Science
in Animal Husbandry

By
H. WILLIAM NEWLAND
1949

This is to certify that the

thesis entitled

Temperature Adaptation in the Baby Pig

presented by

H. William Newland

has been accepted towards fulfillment of the requirements for

Master of Science degree in Animal Husbandry

Geo. O. Brown
Major professor

Date December 7, 1949

TEMPERATURE ADAPTATION IN THE BABY PIG

By

H. WM. NEWLAND

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE

Department of Animal Husbandry

1949

THESIS

TABLE OF CONTENTS

TABLES | Page

FIGURES

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Professor G. A. Brown, Head of the Department of Animal Husbandry, and W. N. McMillen, Associate Professor in Animal Husbandry, for their advice and guidance, and for making this study possible.

Appreciation is also expressed to Professor E. P. Reineke, Department of Physiology, for his timely technical assistance; to Professor Frank Thorp, Jr., Department of Animal Pathology, for his cooperation and advice in the blood studies; and to Miss Sylvia Laine, M. T., Animal Pathology Technician, for making the blood determinations.

INTRODUCTION

Baby pig losses due to environmental factors are of great economic importance to the American farmer. Of these factors, low temperatures represent one of the most important. It is estimated that chilling accounts for three per cent of the baby pig losses. In terms of the average spring pig crop from 1940 to 1949, this means an average of 1,670,000 baby pigs died annually from this cause. Chilling is also responsible indirectly for many other losses. Because of a weakened condition when cold, young pigs are more susceptible to injuries and overlaying by the sow. This problem is of particular importance in the midwest and northern areas where large numbers of pigs are born in severe weather early in the spring.

It is a well known fact that hot environmental conditions are responsible for considerable loss in older pigs. These environmental conditions have been topics for considerable study and research in the fields of housing, heating units, brooders, and ventilation.

Experienced swine producers are familiar with the erect hair, shivering, and huddling of cold young pigs. Observant caretakers also know that the lighter pigs at birth suffer more in cold weather than heavier pigs, often becoming cold to the touch and dying within the first day or two after birth. However, the actual changes taking place in the chilled baby pig and the part played by the heat control mechanism are not fully understood.

The purpose of this investigation was: (1) to study the development of the temperature regulating mechanism and (2) to study the effects of chilling on baby pigs.

REVIEW OF LITERATURE

The Temperature Regulating Mechanism

It has been known for some time that warm-blooded animals have a temperature regulating mechanism at the base of the brain in the hypothalamus. Temperature changes in the environment are reflected in the hypothalamus through the medium of nerve impulses. Barbour (1912) demonstrated that cooling the hypothalamus increased the rectal temperature in rabbits, while heating of this region caused a fall in temperature. Thus, cold evokes the heat production processes while heat arouses the heat loss mechanism. Freund and Strasmann (1912), working with rabbits, and Barbour and Tolstoi (1921), studying dogs, found them to be poikilothermic (body temperature rising and falling with that of the environment) when a transection was made of the lower cervical cord, thereby cutting off the nerve supply to the hypothalamus. That the hair-raising mechanism is under the control of the hypothalamus was shown by Cannon (1932) who found that sympathectomized animals show no erection of hair on exposure to cold.

The development of the temperature regulating mechanism after birth among the homeotherms varies with the species. Depending on environmental temperature, the body temperature in children stabilizes (becomes fully homeothermic) between the first and second years (Kleitman, 1937); in rats, it is about three weeks (Brody, 1943); in chicks, Brody (1945, 1945a), found that the body temperature rises to about 103° the first day, through 104° the second day, and to 106° F. the third day; but, depending on the environmental temperature, takes about three weeks to level off, according to Kleiber (1933).

The temperature regulating mechanism has certain limitations. In this connection, Horvath (1948) has studied the survival time for various species when exposed to -35° C. (these animals were apparently all adults). The mouse was able to survive for 0.4 hours, canary 0.6 hours, rat 0.75 hours to 2.0 hours, rabbit 3.5 to 6.5 hours, and the pigeon 22.0 to 78.0 hours. It was observed that body temperatures dropped preceding death. It is also interesting to note the work of Giaja (1933) who reports the lowest temperature at which various species can maintain their body temperature for one hour to be: pigeon, -85° C.; chicken, -50° C.; rabbit, -45° C.; and rat, -25° C.

Blood Changes and Hormone Influence Under Various Environmental Conditions

Barbour (1921) found that when normal dogs were exposed to high temperatures the blood became diluted, but concentrated when exposed to cold. Barbour and Tolstoi (1923) found the blood solids remained constant in dogs exposed to hot and cold water baths after sectioning the sixth cervical vertebra, thus suggesting this reaction to be under the control of the temperature regulating mechanism. That some of the internal organs increase in water content during this process was shown by Barbour et al. (1933). They found the liver to decrease in the percentage of solids when animals were cooled, but to increase when heated.

It has been demonstrated that hormones play a part in body temperature regulation. Burton (1939) found the thyroid to hypertrophy in animals exposed to cold, and Riddle (1925) found that the thyroid in pigeons grows larger in autumn, suggesting that this gland plans a part in slow adaptation to climate. Although these early observations based on thyroid weight changes are subject to difficulty of interpretation, more recent results on the direct determination of thyroid secretion rates (to be cited later) indicate that thyroid function is markedly increased by exposure to cold.

Glaubach and Pick (1933) found that rabbits treated with thyroxine show no loss in temperature control even when the thalmus is removed, and

Korenchevsky (1926) found that after thyroidectomy cooling causes a much more pronounced fall in body temperature than before removal. Horvath et al. (1938) found that rats exposed to cold respond by greatly increased heat production. The heat production was less when adrenalectomized. Cannon (1932), working with cats, found that the adrenals have the power to increase metabolism when animals are exposed to cold. Brody (1945b) also found that keeping rats in a cold environment for some time raises their basal metabolism.

Blood sugar level has been found to be influenced by body secretions and factors such as low environmental temperature. Cori (1931) states that the mechanism for maintaining a rather constant level of sugar in the blood is intimately connected with the action of insulin and epinephrine secretion. Hartman (1949) states that cold stimulates both the medulla and cortex, and Cannon, McIver, and Bliss showed that hypoglycernia could evoke epinephrine discharge which would raise blood sugar.

As for normal blood sugar in pigs, Madsen et al. (1944) found the average blood sugar to be 140 mg. per 100 cc. blood in normal pigs from birth to twelve-days-old. Hanawalt (1947), in studying hypoglycemia in new-born pigs, found that fasting causes a drop in blood sugar, the intensity depending on the length of time the pigs had nursed before the fasting began.

Kernkamp (1932), Vestal and Doyle (1938), and McMillen and Thorp (1949) found the average hemoglobin level in normal pigs at birth to be 9-13 gm. per 100 cc. of blood. At one week it had dropped to 6-9 gm., in two weeks to 3.5 to 6 gm., and between three and six weeks had almost reached the original level, or 9-12 gm. hemoglobin per 100 cc. blood. Only brief mention was made in the literature reviewed as to the relationship of temperature to hemoglobin levels. However, Howie and his co-workers (1948) observed a hemoglobin drop in eight-week-old pigs raised in cold environments. At three weeks, the hemoglobin levels were comparable to pigs raised in warm environments.

Temperature and Livestock Efficiency

Heitman and Hughes (1949) found the optimum temperature for efficiency and rate of gain to be 75° F. for hogs weighing 70 to 144 pounds and 60° F. for 166 to 260 pound weight groups. Harrlass (1941) found the optimal temperature for milk and fat yield in dairy cattle to be between 50° and 70° F., which agrees with Regan and Richardson (1938) who found that as the temperature increased from 40° to 95° F., milk production gradually dropped from 29 to 17 pounds a day. Rhoad (1935) reports similar findings with European dairy cattle, and Kelley and Rupel (1937) suggest that the optimum stable temperature for dairy animals is about 50° F.

GENERAL EXPERIMENTAL PROCEDURE

Animals Used:

All pigs used in this experiment were from the Michigan State College swine herd. The majority of the pigs were from the Chester White and Duroc breeds. Some crossbred pigs were used in the chilling trials and for collecting the blood data. No attempt was made to distinguish differences between breeds or family lines.

Warm Environmental Conditions:

The warm room consisted of a farrowing pen 8 feet by 11 feet, insulated, and equipped with a heater and thermostat to keep the temperature between 65 and 75 degrees F. The floor and walls were made of wood, and shavings were used for bedding. A continuous record of the temperature was made with a "Brown Recording Thermometer." For the data collected under "barn" conditions, the pigs were farrowed in the central farrowing house at the Michigan State College swine barn. These were 8 feet by 8 feet concrete pens equipped with a 200-watt heat lamp in an open brooder. In severe weather, an electric heater kept the temperature above 50 degrees F.

Cold Environmental Conditions:

A standard walk-in meat cooler with a temperature of 34 degrees F. was used for all of the chilling trials of short duration (two to three hours). For the chilling trials of longer duration, sows were farrowed in a farrowing pen 8 feet by 11 feet, in a barn with no source of heat. During the time which data were taken, a continuous record of temperature was taken with a "Brown Recording Thermometer."

Body Temperature Data:

All body temperatures were taken rectally with a clinical thermometer recording in tenths of a degree Fahrenheit. The thermometer was inserted to approximately 1.5 inches and held for at least 60 seconds.

THE DEVELOPMENT OF THE TEMPERATURE REGULATING MECHANISM IN THE BABY PIG

Procedure

Body temperatures were taken of pigs at various ages after birth, starting with one-half hour and at regular intervals of 6, 12, 24, 36, and 48 hours, and in some cases continuing up to ten days. Where a more complete comparison between pigs was desired, such as differences due to weight, temperatures were taken at ten minute intervals during the first hour after birth. Accurate birth weights were recorded for the purpose of comparing different sized pigs.

For a comparison of the rate at which body temperature regulation is developed under different environmental conditions, litters were farrowed in a warm room, 65°-75° F., and compared with pigs farrowed in a cold room, 25°-35° F.

Results

Body Temperature Under Average Conditions

The average temperature responses of 25 pigs under barn conditions (environmental temperatures between 55° and 75° F.) show that the temperature of a new-born pig drops from 3° to 12° F. during the first hour after birth, with the average being about 4° F., as seen in Figure 1. The sharpest drop occurs during the first 20 minutes of life, and by the time the pig is an hour old, there is a gradual increase toward normal. The average temperature of 25 pigs observed was 98° F. at 20 minutes, 100.5° at 10 hours, 101.5° at 24 hours, and 102.3° at 48 hours.

Body Temperature Development Compared Under Warm and Cold Environments

The average body temperature drop of 16 pigs with an average birth weight of 2.5 pounds, born in the warm room, was 3 degrees during the first half

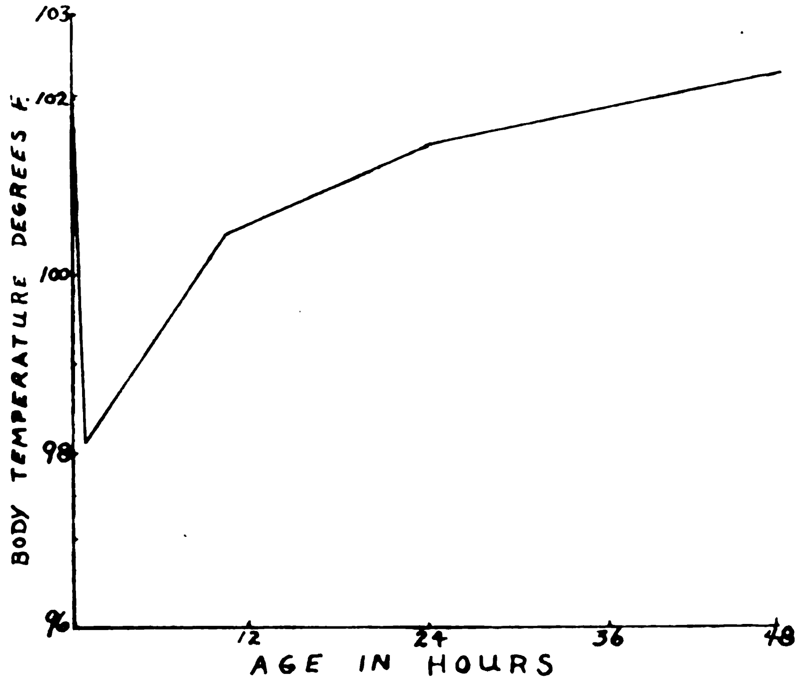


Figure 1. Relationship of age to body temperature in pigs up to two-days-old under average barn conditions (55°-75° F.)

hour after birth, the average at this age being 100.0° F. At one-hour-old, they showed a gradual increase of 100.2°, and by the time the pigs were 48-hours-old the average body temperature was 102.0°, at 72 hours 102.2°, and at 96 hours had reached 102.4° F., or almost back to normal. (See Figure 2).

The body temperature of the 19 pigs with an average birth weight of 2.4 pounds, born and raised in the cold, dropped lower during the first half hour of life, and the return to normal was at a slower rate than those born in the warm room, as can be seen in Figure 2. The average drop for this group was 7.3 degrees at one half hour, or to a temperature of 95.7° F. However, like those in the warm room, they showed a definite climb back toward normal. At one hour the average was 96.2°, in 48 hours 100.7°, in 72 hours 101.4°, and in 96 hours 101.6° F.

At ten-days-old the pigs raised in the warm room showed an average body temperature of 102.7° F., while those raised in the cold averaged 102.1° F.

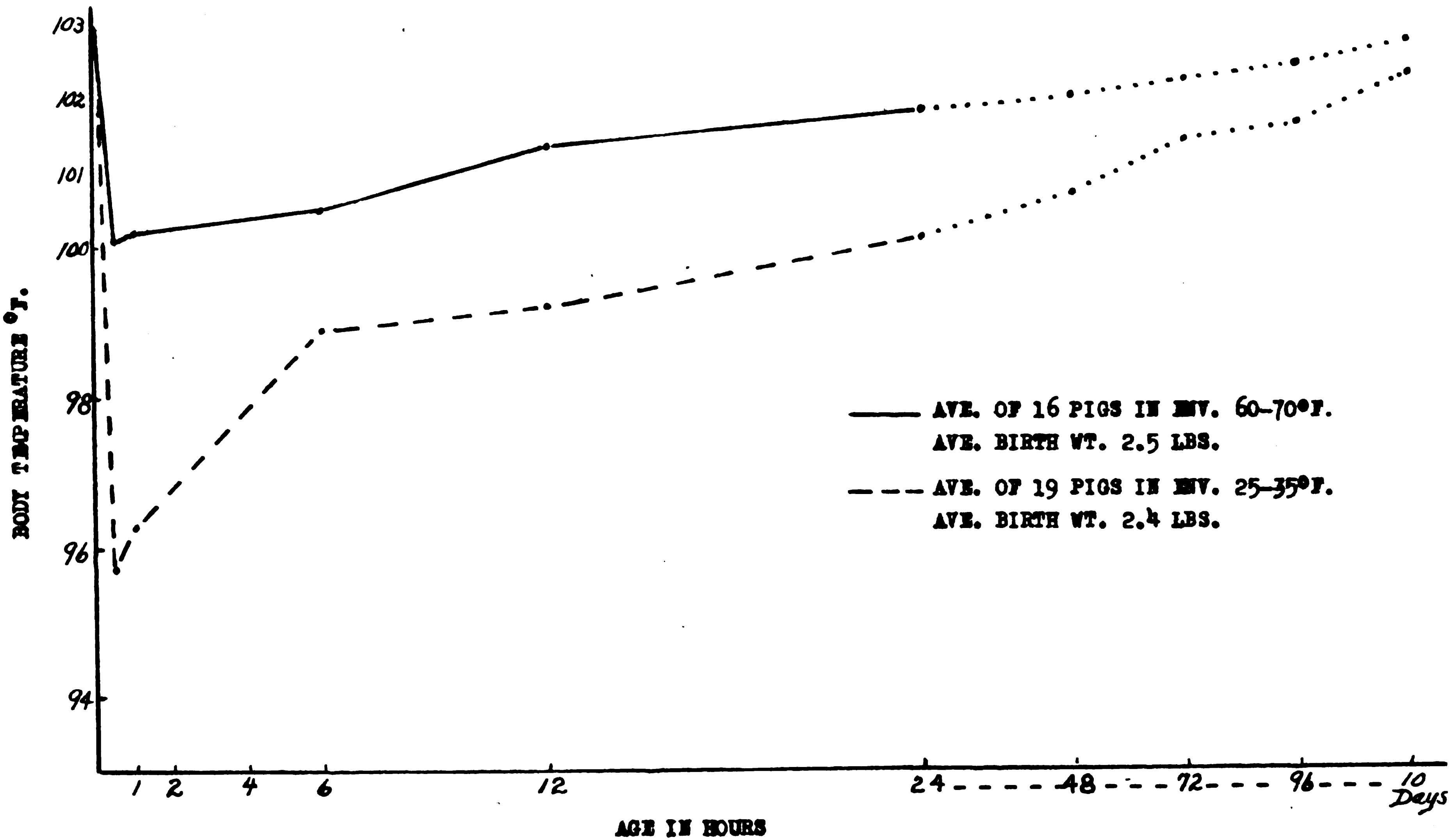


FIGURE 2. A COMPARISON OF BODY TEMPERATURE DROP IN PIGS RAISED IN WARM AND COLD ENVIRONMENTS

It happened that all the pigs in the warm room weighed over 2 pounds at birth. However, there was more variation in the size of the pigs born in the cold. Accordingly, the temperature patterns of the different weight groups in each environment are shown in Table 1.

Table 1. A Comparison of Birth Weights and Body Temperatures of Pigs Raised Under Different Environmental Conditions

	No. Pigs	Av. Wt.	Body Temperature Pattern with Increase in Age (°F.)						
			½ Hr.	1 Hr.	6 Hrs.	12 Hrs.	24 Hrs.	48 Hrs.	72 Hrs.
In warm room	16	2.5	100.0	100.2	100.5	101.3	101.8	102.0	102.2
In cold room (over 2 lbs.)	15	2.7	96.1	97.2	99.6	99.6	100.2	100.9	101.5
In cold room (under 2 lbs.)	4	1.4	93.0	91.4	94.9	97.1	99.7	100.3	102.1

During the first hour after birth no shivering nor "hair raising" was observed in the pigs in the warm room, but was exhibited by those in the cold.

There was a correlation of +.766 between age and body temperature development in these two groups of pigs, and a correlation of +.968 between the body temperatures of the pigs raised in the warm room and those raised in the cold. The range in body temperatures in the two groups is given in Table 2.

Table 2. Range in Body Temperatures of Pigs up to 48-Hours-Old and Under Warm and Cold Environments

	½-Hour-Old		1 Hour Old		12-Hours-Old		24-Hours-Old	
	Av. °F.	Range °F.	Av. °F.	Range °F.	Av. °F.	Range °F.	Av. °F.	Range °F.
Pigs born and raised in warm room 65°-75° F.	100.1	96.0-101.8	100.3	95.0-102.0	101.3	100.4-101.9	101.8	98.6-102.0
Pigs born and raised in cold room 25°-35° F.	95.7	92.0-99.0	96.3	90.0-100.0	99.2	94.2-101.4	100.7	98.6-101.0

Size as a Factor in Body Temperature Regulation

It may be seen from Figure 3 that the temperature of the lighter pigs dropped faster than that of the heavier pigs. In the litters used, there was a positive intra-litter correlation of 0.71 between the birth weights of pigs and the drop in body temperature after birth. Although the data are limited, similar slopes of the regression lines of these litters and the high correlation coefficient give the data significance. These results would be expected from the work of Brody et al. (1945c). He states that "The basal heat production per unit of body weight in homeotherms decreases rapidly with increasing weight." Also from the laws of Newton is derived the fact that the heat loss from a body is proportional to its surface area. These two statements translated into terms of this experiment seem to explain the greater temperature drop in the light pigs. This would be expected, as the lighter pig must produce more heat per unit of body weight to maintain normal temperature. The lighter pig also has proportionately more surface area from which to radiate heat than a larger pig.

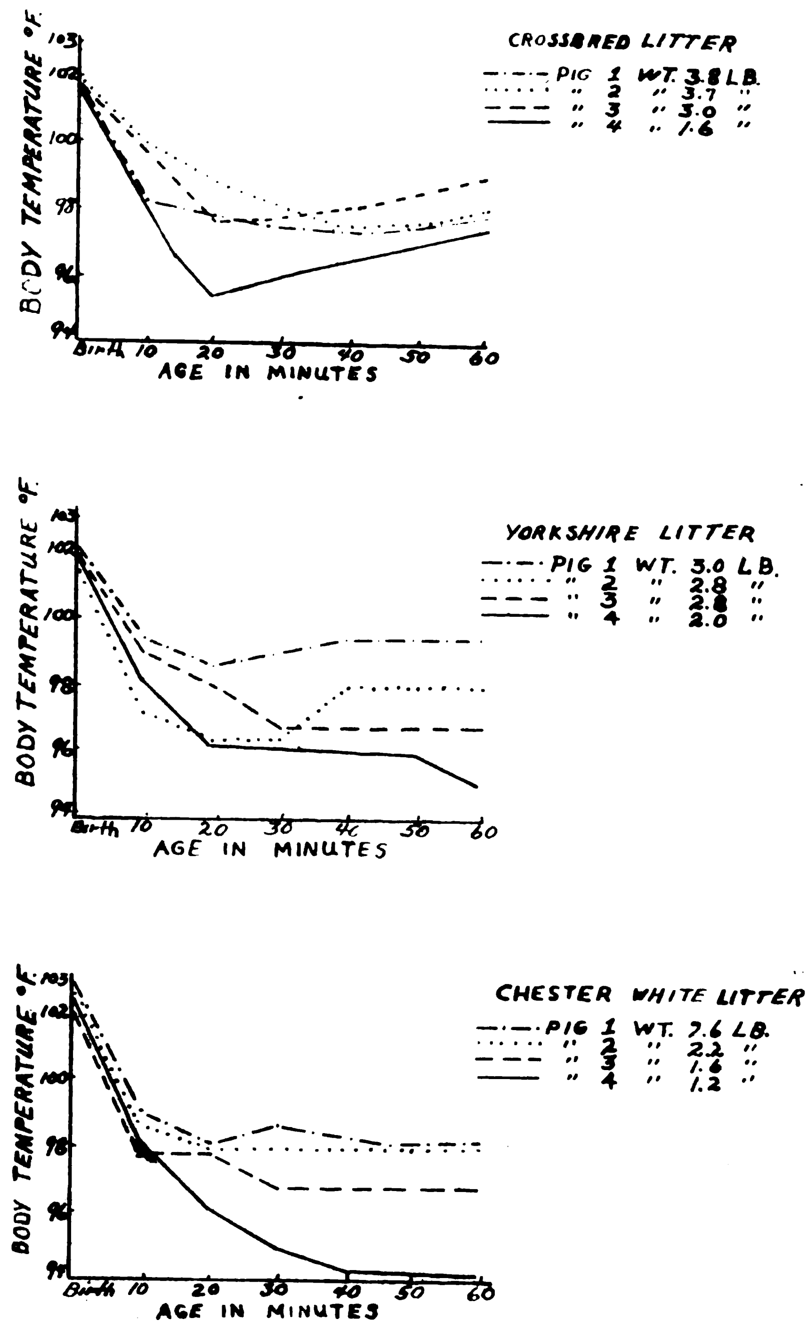


Figure 3. Relation of body weight to temperature drop in baby pigs.

Discussion

Cannon (1929) has shown that homeothermic mechanisms are not required by the developing mammal before birth. At birth and thereafter, however, survival becomes increasingly contingent upon the exercise of these mechanisms, and so poikilothermic embryos develop into homeothermic adults.

The sudden drop of body temperature after birth in the baby pig indicates a lack of development in the temperature regulating mechanism. The temperature development curves in Figures 1 and 2 seem to graphically display Cannon's theory. This is in agreement with the findings of Brody (1945a) in chicks. It can be seen from Figures 1 and 2 that at two-days-old pigs born in warm environments had practically reached the temperatures of their mothers, or 102.5^{o}, which is reported by Dukes (1943) to be the normal body temperature for swine.

It is evident that the amount of drop and length of time required to gain full control of body temperature is directly related to the environmental temperature.

The fact that the pigs in the cold room regained normal body temperature more slowly than those in the warm room would imply that the mechanism for heat production is underdeveloped at this age. Barbour (1941) found this heat production mechanism present at birth in some species, but absent in others. However, in the blood data reported later, it was found that the glucose increases in a one-day-old chilled pig, indicating a mechanism for increased heat production.

Metabolism was probably higher in the pigs raised in the cold environment, as was shown by Brody (1945b) working with rats. It was not possible to check metabolism in this study, but it is apparent that any increase in metabolism did not entirely compensate for the lower body temperature.

Other factors related to temperature regulation are shivering and the "raising" of the hair, and are under the control of the hypothalamus (Ranson, 1940). It would seem that this particular mechanism is quite well developed in the baby pig, since at about one-hour-old it was observed that the pigs born in the cold were shivering and that the hair was standing erect. For typical chilled pigs two-days-old, see Figure 4.

Figure 4. Typical Chilled pigs at two-days-old. Environmental temperature 34° F.

Note the erect hair, wrinkled skin, humped position, and general huddling.

THE EFFECTS OF CHILLING ON BABY PIGS

Procedure

Age and Birth Weight Studies:

Two age groups were used in this part of the study; pigs from birth to four-hours-old, and another group 18 to 24 hours. When pigs were chilled immediately after birth, the temperature of the sow was taken as the original pig temperature since they were found to be comparable. All chilling data were collected by placing the pigs in a standard meat cooler, with the exception of those chilled immediately after birth, in which case the sows were farrowed in environments comparable to the cooler, or 30° to 34° F.

Each age group was divided into two weight groups; those under two pounds and those weighing two pounds and over at birth.

Studies on Blood Changes:

In the observations of blood changes in chilled pigs, approximately 1.5 cc. blood samples were taken with needle and syringe from the anterior venous sinus immediately before chilling and immediately after. Blood hematocrits were run by the Wintrobe method, blood sugars by the Folin modification of Folin-WU method, and hemoglobin by the Photelometric method.

Results

Relationship of Size to Temperature Response in Chilled Pigs

PIGS CHILLED BETWEEN BIRTH AND FOUR-HOURS-OLD—Table 3 gives a comparison of 15 heavy pigs (2 lbs. and over at birth) and 9 light pigs (under 2 lbs.) and their temperature response when chilled during the first four hours after birth. The ages ranged from birth to four hours, and were chilled for two hours at 34° F. The average birth weight for the larger pigs was 2.8 pounds,

Table 3. The Relationship of Birth Weight in Pigs to Body Temperature Drop When Chilled*

Age Range - Birth to 4-Hours-Old

Pigs Weighing Over 2 Pounds at Birth

Pig No.	Birth Weight Lbs.	Body Tempt. Before Chilling °F.	Body Tempt.-°F. After Chilling 2 Hrs. @ 34° F.
12	3.5	103.0	99.0
13	2.3	103.0	94.7
14	2.5	103.0	96.4
15	2.5	103.0	97.0
17	3.1	103.0	97.0
1-10	3.0	103.0	95.8
1-11	2.8	103.0	96.4
82	3.1	101.4	92.0
85	3.4	100.4	100.2
8-11	2.8	100.1	100.1
32	2.8	103.0	97.0
33	2.8	103.0	97.8
34	2.8	103.0	98.6
37	2.7	103.0	99.8
36	2.5	103.0	100.0
Av.	2.8	102.5	97.5

Pigs Weighing Under 2 Pounds at Birth

11	1.3	103.0	90.0
16	1.5	103.0	92.5
18	1.7	103.0	93.0
19	1.0	103.0	90.0
86	1.6	98.6	90.0
8-12	1.6	99.6	90.0
8-13	1.7	98.4	90.0
8-14	1.1	96.0	90.0
21	1.1	102.0	91.0
Av.	1.4	100.1	90.7

*Correlation of birth weight (x) to temperature after chilling (y).
rxy = +.760

Table 4. The Relationship of Birth Weight in Pigs to Body Temperature Drop When Chilled*

Age Range - 18 to 24-Hours-Old

Pigs Weighing Over 2 Pounds at Birth

Pig No.	Birth Weight Lbs.	Body Tempt. Before Chilling °F.	Body Tempt.-°F. After Chilling 3 Hrs. @ 34° F.
61	2.3	102.6	100.8
62	2.6	102.2	101.2
64	2.5	102.0	101.0
65	2.1	102.2	98.6
69	2.0	101.4	99.6
33	3.8	101.2	98.6
39	2.4	101.2	100.4
Av.	2.2	101.7	99.9

Pigs Weighing Under 2 Pounds at Birth

63	1.7	101.6	99.0
66	1.4	101.2	90.0
67	1.1	100.3	92.0
6-10	1.7	101.0	99.0
6-11	1.4	101.5	98.6
36	1.9	98.6	96.0
38	1.7	97.8	91.0
Av.	1.55	100.3	95.1

*Correlation of birth weight (x) to temperature after chilling (y). $r_{xy} = +.584$

the range being from 2.3 to 3.5 pounds. Before chilling, the average body temperature of this group was 102.5°, and after chilling 97.5° F. The average body temperature drop after chilling was 5.0°, the range being from 0.2° to 9.4° F.

The smaller pigs in this age group averaged 1.4 pounds, the range being from 1.1 to 1.7 pounds. Before chilling, the average body temperature of these small pigs was 100.1° and after chilling 90.7° F., or a drop of 9.4°, and ranged from 6.0° to 13.0° F.

There was a correlation of +.760 between birth weight and temperature after chilling for these 24 pigs.

PIGS CHILLED AT 18 to 24-HOURS-OLD—Table 4 gives a comparison of 7 heavy and 7 light pigs and their temperature response to chilling at about one-day-old. The larger pigs had an average birth weight of 2.2 pounds, ranging from 2.1 to 3.8 pounds. The average drop in body temperature after chilling three hours at 34° F., was 1.8°, ranging from 0.8° to 2.4° F.

The smaller pigs in this age group averaged 1.55 pounds at birth and ranged from 1.1 to 1.9 pounds. Before chilling these pigs had an average body temperature of 100.3°, and afterwards 95.1° F. The average drop in body temperature was 5.2°, range 2.0° to 11.2° F.

There was a correlation of +.584 between birth weight and temperature after chilling for these 14 pigs.

For a further comparison of individual pigs of various sizes and temperature drop when chilled, see Tables 8, 9, and 10.

Discussion

It can be seen from Tables 3 and 4 that small pigs (under 2 pounds) at birth have a much sharper body temperature drop when chilled than pigs over 2 pounds. It can also be seen that very young pigs in both weight groups drop a little lower when chilled than pigs about one-day-old. The explanation for this has already been discussed briefly under the section on the temperature regulating mechanism, namely, that "the basal heat production per unit of body weight in homeotherms decreases rapidly with increasing weight," and the fact that heat loss from a body is proportional to its surface area. It may also be assumed that one-day-old pigs have a better developed temperature regulating mechanism than pigs at birth.

In this particular group of pigs, only one died directly from chilling during the course of the experiment. Another became weak from chilling and was overlaid by the sow. It should be pointed out here that several times in the chilling experiments very small pigs became weak to the point of being unable to stand before the end of the chilling period, but in most every case revived when warmed and were normal in every respect. (See Figure 7). However, it is a common observation that many small pigs become chilled at low temperatures and die or are killed by overlaying.

These data indicate that many of the smaller pigs are unable to withstand freezing temperatures for more than a few hours. In this connection, Horvath (1948), in studying survival time of various species at low temperatures, found the body temperatures to drop preceding death.

Baby pigs are obviously very responsive to low environments, depending greatly on the size and age after birth. There are, no doubt, other factors involved in reactions of young pigs to low temperatures other than body temperature reported here. Milking ability of the sow, time elapse between birth and nursing, and fasting (see Figure 7) are related to the pig's ability to withstand low temperatures and should be studied further.

Case Histories on Two Litters of Pigs Born and Raised in Cold vs Warm Environments

Questions are often raised regarding the growth and development of pigs born and raised in warm environments as compared to cold. Also, since many pigs die of chilling, it is of interest to observe the after effects of those which survive.

Accordingly, two litters of pigs were farrowed at approximately the same time; one in a controlled environment at 65 to 70° F., the other in a pen ranging from 25° to 35° F. the first two weeks and 35° to 40° the third week. An accurate record of temperature during each hour of the day was recorded on a recording thermometer (see Figure 5). Humidity records were observed daily using a sling cycrometer. Shavings were used for bedding in each pen and each had guard rails around the sides. Weight records were kept up to weaning time (56 days).

OBSERVATIONS AND DISCUSSION—Neither sow had trouble at farrowing time, and both had ample milk from the start. The sow in the cold room appeared to be the better mother, or perhaps was using nature's instinct by lying with her udder along the guard rail so the pigs could huddle together for all the heat possible. She continued to do this until the pigs were too large to conveniently nurse when close to the rail.

Growth response and body temperature patterns for each pig in the two groups are presented in Tables 5 and 6. It can be seen from the tables that while the average birth weights for the two litters were about the same, 2.7 and 2.5 pounds, there was much more variation in the size of the pigs born in the cold. The humidity averaged 24 percent higher in the cold room, which made the cold environment all the less favorable. Lozinsky (1923) found that dogs were less able to regulate body temperature in cold moist air than in cold dry air.

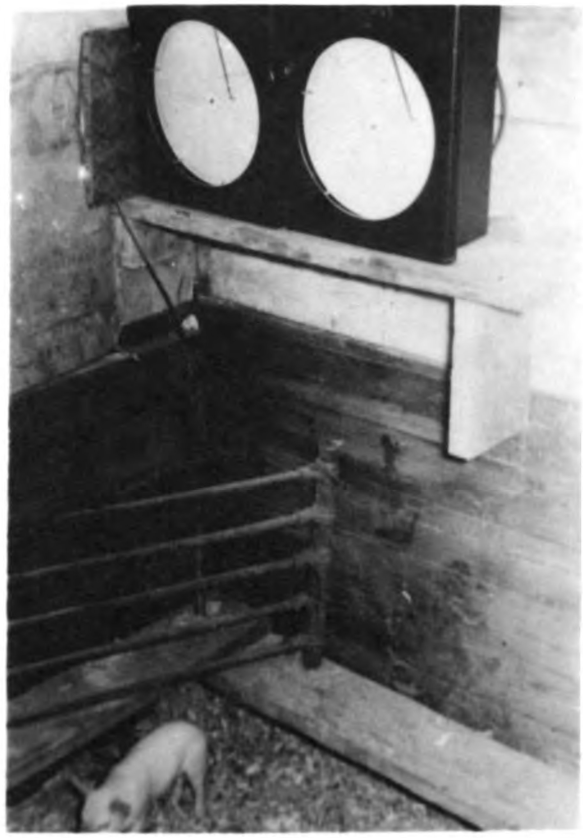


Figure 5. Control room (farrowing pen) used for the "warm" environmental trials. Top photo shows recording thermometers; one for the room shown, the other recording the temperature of the "cold" room in the next pen. Bottom photo: A crossbred litter in the warm room.

Table 5. Effect of Environmental Temperature on Growth and Development of Pigs:

I. Case History of a Litter of Pigs Born and Raised Under Controlled

Environmental Temperature of 65°-70° F.

Chester White x Berkshire Crossbred Pigs Farrowed 3-6-49

Pig No.	Birth Weight Lbs.	10 Day Weight Lbs.	21 Day Weight Lbs.	56 Day Weight Lbs.	Body Temperature Pattern °F.		
					at one hour	at 6 hours	at 48 hours
21	2.2	5.9	10.4	26.9	100.2	101.0	102.0
22	2.5	4.5	7.1	27.0	95.0	97.8	101.4
23	2.6	6.3	11.2	29.4	100.8	101.0	101.8
24	3.3	5.7	*	----	101.6	101.0	101.8
25	3.1	6.1	10.0	29.4	101.6	101.3	102.4
26	2.4	5.4	10.1	26.9	100.6	99.8	102.0
27	2.9	6.8	11.6	28.2	100.1	101.2	102.3
28	3.0	6.7	11.1	29.4	101.0	100.8	102.2
29	2.6	6.2	9.6	19.2	102.0	100.8	102.4
Av.	2.7	5.97	10.1	27.1	100.3	100.5	102.0

*Accidentally killed.

Average humidity during first 10 days was 60%,

the range being from 45 to 70%.

Table 6. Effect of Environmental Temperature on Growth and Development of Pigs:

II. Case History of a Litter of Pigs Born and Raised in a Barn

Under Natural Conditions Except for No Heat or Brooder.

Environmental Temperature First 2 Weeks 25°-35° F., Third Week 35°-40° F.

Duroc x Yorkshire Crossbred Pigs Farrowed 3-5-49*

Pig No.	Birth Weight Lbs.	10 Day Weight Lbs.	21 Day Weight Lbs.	56 Day Weight Lbs.	Body Temperature Pattern °F.		
					at one hour	at 6 hours	at 48 hours
12	3.5	7.4	11.9	32.2	99.0	101.8	100.6
13	2.3	5.5	7.9	26.1	94.7	99.6	102.0
14	2.5	4.8	8.0	24.8	96.4	96.2	100.0
15	2.5	6.1	10.6	32.2	97.0	100.2	102.0
16	1.5	Overlaid by sow at one-day-old.			92.5	94.8	---
17	3.1	6.7	10.4	26.1	97.0	100.6	101.2
19	1.0	Died from chilling at 2-hours-old			90.0	---	---
1-10	3.0	6.1	9.6	26.0	95.8	99.6	101.0
1-11	2.8	6.0	10.1	29.8	96.4	100.8	101.4
Average	2.5				94.7	98.3	100.9
Average Exclud. 16 & 19	2.8	6.1	9.8	28.2			

*All pigs under 2 pounds that survived were excluded from this study.

The average humidity during the first 10 days was 84%,

the range being from 74 to 92%.

It can be seen from Table 6 that only one pig died from chilling. This pig weighing only one pound at birth nursed, but at one-hour-old its body temperature had dropped to 90° F.; it was lying on the floor, too weak to rise. A pig weighing 1.5 pounds may have died indirectly from a weakened condition due to chilling, but was actually overlaid by the sow.

At three weeks of age, the pigs were removed from the above mentioned environments and raised in a standard hog house under normal April environment. At weaning time, it was not possible to distinguish any difference in general vigor and thriftiness between pigs of comparable birth weights raised under the two environmental temperatures during the first three weeks.

In three weeks, the pigs raised in the warm room weighed an average of 10.1 pounds as compared to 9.8 pounds for those raised in the cold. At weaning time (56 days), the pigs raised in the warm environment during the first three weeks averaged 27.1 pounds in weight as compared to 28.2 pounds for those raised in the cold. This increase in gains approaches statistical significance. Although no conclusions can be drawn from the observation at present, it is well established that certain of the hormones known to stimulate growth are influenced by exposure to cold. Dempsey and Astwood (1943) found a five-fold increase in thyroid secretion in rats when moved from an environment of 35° C. to 1° C. Also, Reineke and Turner (1945) found the thyroid secretion in chicks during the months of October and November to be almost double the secretion during the summer time. These workers also found that the thyrotrophic hormone secretion followed the same pattern as the thyroid hormone. From this, it might be concluded that cold normally acts as a stimulus to the pituitary to secrete thyrotrophin and so increase the supply of the thyroid hormone. That increased thyroid activity is rather slow but steady in animals exposed to cold environments, was shown by Leblond et al. (1943) who found the maximum fixation of radioiodine by the thyroid of rats to be 26 days after exposure to an environment of 0° to 2° C.

Results of these limited observations in young pigs indicate that unless complications develop, such as disease and poor nutrition, there are no adverse effects resulting from exposure to an environment near freezing temperature during early life, in surviving pigs.

Blood Changes in Pigs Exposed to Chilling Temperatures

BLOOD HEMATOCRIT (CELL VOLUME) RESPONSE--Blood samples taken before and after chilling at 34° F. and analyzed for concentration of cells, showed a definite drop (blood dilution) in young pigs 2 to 4-days-old (Table 7a). Seven pigs in litter number 20 which were two-days-old at the time of the experiment, dropped from an average hematocrit of 34.0% before chilling to 26.8% afterwards, or an average drop of 7.2%. These pigs averaged 2.7 pounds at birth and showed an average body temperature drop during the chilling of 2.7° F. Three pigs in litter number 40 and five pigs in litter number 60, which were three and four-days-old, respectively, also showed an average blood dilution when chilled. The average decrease in concentration in these litters was 8.7 and 4.4%, while the body temperature drop averaged 0.2° and 0.3° F., respectively. Individual pig variation can be seen in Figure 6.

As the pigs grew older, chilling caused almost no change in blood concentration. At 10-days-old, six pigs from litter number 20 increased 0.6% in cell concentration and at 23 days a decrease of 0.8%. At 27-days-old, the three pigs in litter number 40 also had less change in concentration, dropping an average of 1.5% (Tables 7b and 7c).

Table 7. Blood Response in Pigs Exposed to Chilling:
Changes in Blood Hematocrit (Cell Volume) and Hemoglobin
in Pigs of Various Ages

a. Pigs 2 to 4-Days-Old

Litter Number	No. Pigs	Av. Hematocrit - % Before Chilling	Av. Hematocrit - % After Chilling*	Av. Hemoglobin-gm/100cc Before Chilling	Av. Hemoglobin-gm/100cc After Chilling*	Body Temp. - °F. Before Chilling	Body Temp. - °F. After Chilling*
20	7	34.0 ± 5.9	26.8 ± 7.5	10.2	not run	102.1	99.4
40	3	33.7 ± 3.3	25.0 ± 2.2	9.5	7.9	101.8	101.6
60	5	33.0 ± 5.1	28.6 ± 5.4	9.8	9.1	102.0	101.7

* Chilled 3 hours at 34° F.

b. Pigs 10 to 12-Days-Old

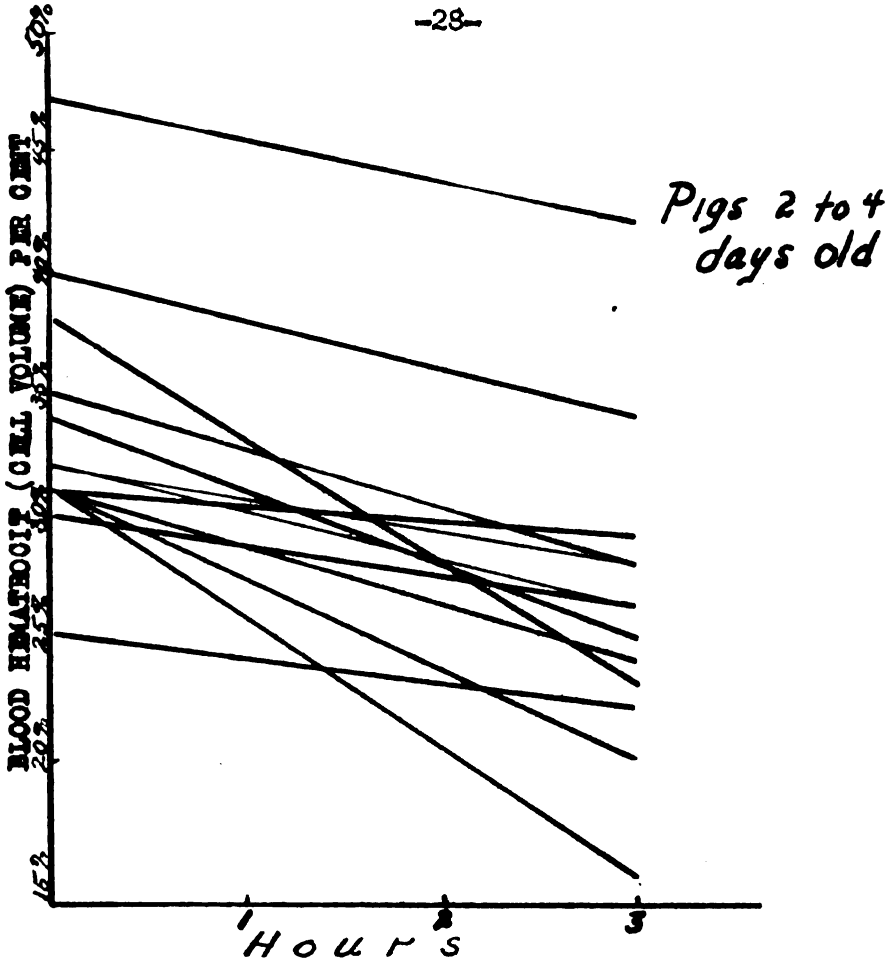
Litter Number	No. Pigs	Av. Hematocrit - % Before Chilling	Av. Hematocrit - % After Chilling*	Av. Hemoglobin-gm/100cc Before Chilling	Av. Hemoglobin-gm/100cc After Chilling*	Body Temp. - °F. Before Chilling	Body Temp. - °F. After Chilling*
20	6	30.2 ± 2.4	30.8 ± 2.8	10.2	9.5	102.8	101.8

*First sample taken while pigs were still in warm room. Second sample taken after sow and litter were in hog house overnight. (Av. temp. 25° F.)

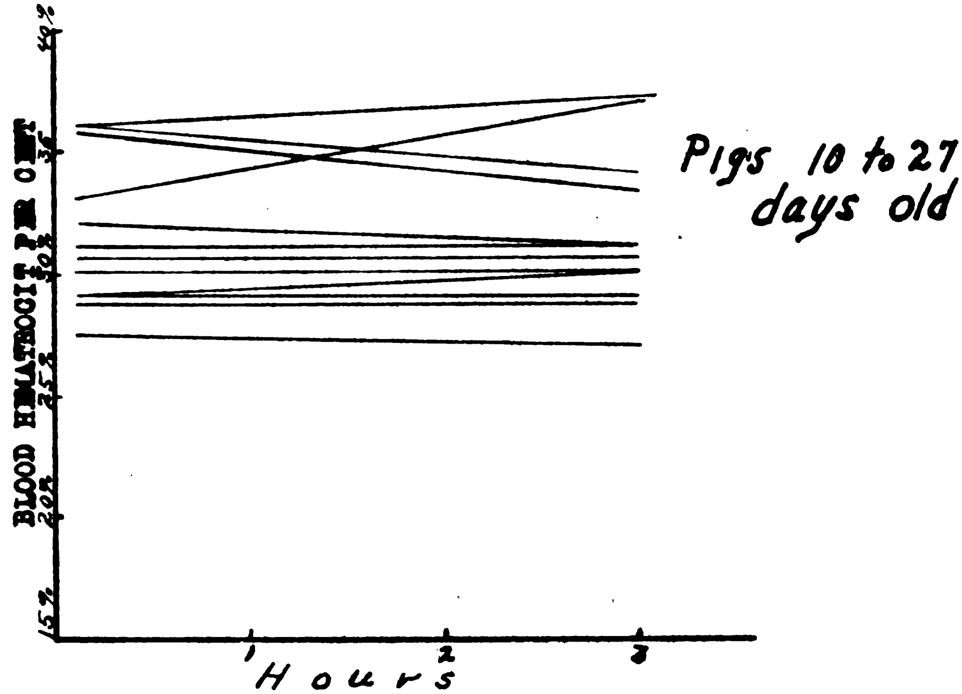
c. Pigs 23 to 27-Days-Old

Litter Number	No. Pigs	Av. Hematocrit - % Before Chilling	Av. Hematocrit - % After Chilling*	Av. Hemoglobin-gm/100cc Before Chilling	Av. Hemoglobin-gm/100cc After Chilling*	Body Temp. - °F. Before Chilling	Body Temp. - °F. After Chilling*
20	6	33.1 ± 3.0	32.3 ± 3.4	10.9	10.9	102.8	101.7
40	3	24.3 ± 6.5	22.8 ± 7.3	7.7	7.6	---	---

*Chilled 4 hours at 34° F.



BLOOD HEMATROCIT (CELL VOLUME) CHANGE WHEN CHILLED 3 HOURS AT 34° F.



BLOOD HEMATROCIT (CELL VOLUME) CHANGE IN PIGS WHEN CHILLED 3 HOURS AT 34° F.

Figure 6

It can be seen from the tables that even two and three-week-old pigs exhibit some temperature drop when chilled. However, litter 20 was exposed to quite severe temperatures at ten-days-old; overnight at an average temperature of 25° F. This procedure was followed to get a comparison of the rate of the water-shifting response since all the other determinations were made on the basis of a 3 to 4 hour chilling period. Again at 23 days, litter 20 dropped an average of 1.1° in body temperature when chilled at 34° F. for four hours. Body temperatures were not taken of litter 40 during the latter chilling period.

It can be seen from Figure 6 that the general trend in blood concentration is downward when very young pigs are chilled, or an actual blood dilution; some pigs reacted more drastically than others. On the other hand, two to three-week-old pigs in this experiment quite consistently exhibited little or no change at all in blood concentration, and in a few cases, actually showed blood dilution.

Discussion:

Age of the pigs at the time of chilling seems to have an important influence on the hematocrit change. From Table 7 and Figure 6, it can be seen that the young pigs (up to four-days-old) showed a definite drop in cell concentration while the ten-day and three-week-old pigs remained about the same. This means that the young pigs used in this experiment actually had an increase in the water content of the blood, thereby causing a decrease in cell concentration. In the older pigs, there was apparently no shifting of water in either direction; the blood cell concentration remaining almost unchanged.

Blood dilution (decrease in cell volume) shown in the young pigs is in reverse from an animal with a normally functioning temperature regulating mechanism, according to Barbour (1923). He found that dogs respond regularly to a moderately high environmental temperature by blood dilution and to a cold environmental temperature by blood concentration.

Pigs about two to three-weeks-old showed very little hematocrit change in either direction (Tables 7b and 7c). This would seem to indicate further the lack of development of the temperature regulating mechanism in very young pigs; gradually becoming adapted to low environmental temperatures at two to three-weeks-old. At just what age the pig shows the normal blood concentration reaction when cooled, was not determined in this study since no pigs over three weeks of age were used in the blood determinations.

BLOOD SUGAR RESPONSE IN CHILLED PIGS--

Pigs fasted 8 hours previous to chilling: Blood glucose changes in one-day-old pigs when chilled three hours at 34° F. after an eight hour fast, are shown in Table 8. The average of five pigs before chilling was 73.3 mg. of glucose per 100 cc. blood. After being exposed to an environmental temperature of 34° F. for three hours, the glucose had increased to an average of 99.6 mg. per 100 cc., or an increase of 26.3 mg. The range before chilling was from 69.0 to 80.0 mg. per 100 cc., and after chilling from 71.1 to 115.0 mg. Three control pigs left under the brooder away from the sow during the three hour period averaged 51.5 mg. at the beginning and 50.1 mg. per 100 cc. at the end, or almost no change. The body temperatures of the control pigs remained the same while the chilled pigs dropped an average of 1.1° F.

That the lower average glucose content of the control pigs was merely chance, is evident from Table 8, since pig number 13 had a glucose content of 71.1 mg. in the first and 75.5 mg. per 100 cc. in the second sample.

Pigs fasted 5 hours previous to chilling: Pigs in this group also exhibited an increase in blood sugar when chilled, as seen in Table 9. While the average for

Table 8. Blood Response in Pigs Exposed to Chilling:

Changes in Blood Sugar, Hematocrit (Cell Volume), and Hemoglobin

One-Day-Old Pigs on 8 Hour Fast Before Start of Experiment

Pig No.	Birth Weight Lbs.	Glucose mg/100 ml. Blood		Hemoglobin gm/100 cc.		Hematocrit %		°F. Body Temperature	
		Before Chilling	After Chilling **		**		**		**
12	2.8	71.1	105.7	10.8	11.4	32.5	33.0	101.0	100.8
14	3.4	69.0	71.1	12.5	11.8	34.5	35.5	101.0	100.8
16	3.0	80.0	97.5	12.5	11.8	34.0	33.5	101.0	100.0
17	2.4	69.0	108.6	10.8	10.2	29.5	29.0	102.0	100.4
18	2.6	77.7	115.0	9.8	10.3	28.0	31.0	101.2	98.8
11*	2.8	40.0	38.3	8.6	7.2	24.0	20.0	101.2	100.6
13*	3.0	71.1	75.5	10.8	10.1	30.0	30.0	101.0	98.8
15*	3.2	43.3	36.6	11.8	10.2	33.0	32.5	101.0	101.0
Av. of Control Pigs		51.5*	50.1	10.4	9.2	29.0	27.5	101.1	100.1
Av. of Chilled Pigs		73.3	99.6	11.3	11.1	31.7	32.4	101.2	100.1

* Control pigs - left under brooder, away from sow.

**Chilled 3 hours at 34° F.

Table 9. Blood Response in Pigs Exposed to Chilling:

Changes in Blood Sugar, Hematocrit (Cell Volume), and Hemoglobin

One-Day-Old Pigs on 5 Hour Fast Before Start of Experiment

Pig No.	Birth Weight Lbs.	Glucose mg/100 ml. Blood		Hemoglobin gm/100 cc.		Hematocrit %		°F. Body Temperature	
		Before Chilling	After Chilling **		**		**		**
15-2	2.7	92.50	97.50	9.5	8.3	27.0	25.0	101.8	100.4
15-3	2.0	32.14	55.46	9.2	9.5	36.0	27.5	101.4	98.2
15-5	1.2	25.00	48.30	9.5	8.1	29.0	25.0	100.6	90.0
15-10	1.5	73.33	25.00	11.1	11.1	28.0	34.0	98.4	90.0
15-11	1.4	33.57	35.00	10.8	8.3	34.0	26.5	101.0	90.0
15-1*	2.7	87.50	78.88	10.8	10.1	30.0	28.0	101.4	102.4
15-9*	1.6	53.64	50.00	11.4	10.1	34.0	33.0	101.6	101.6
Av. of Control Pigs		70.60	64.40	11.1	10.1	32.0	30.5	101.5	102.0
Av. of Chilled Pigs		51.30	52.30	10.0	9.1	30.8	27.6	100.6	93.7
Av. of Chilled Pigs Excluding No. 15-10		45.80	59.10			31.5	26.0		

* Control pigs - left under brooder, away from sow.

**Chilled 2 hours at 34° F.

Note: Pigs 15-11, 15-9, and 15-10 had gone into a slight coma at the end of two hours chilling and were lying in a prone position, too weak to stand. (See pictures). After warming under the brooder for three hours, they were up and nursing.

Table 10. Blood Response in Pigs Exposed to Chilling:

Changes in Blood Sugar, Hematocrit (Cell Volume), and Hemoglobin

One-Day-Old Pigs Fasted 3 Hours Before Start of Experiment

Pig No.	Birth Weight Lbs.	Glucose mg/100 ml. Blood		Hemoglobin gm/100 cc.		Hematocrit %		°F. Body Temperature	
		Before Chilling	After Chilling **		**		**		**
12-1	2.8	105.7	128.3	11.8	8.6	35.0	24.0	102.0	99.3
12-2	3.5	97.5	160.0	9.8	8.6	28.5	27.0	101.0	98.0
12-4	2.0	85.0	125.0	9.2	8.9	31.0	26.5	101.6	100.4
12-6	3.1	66.0	115.0	12.9	12.5	48.0	42.0	102.6	99.8
12-8	2.6	108.6	155.0	10.1	8.9	26.0	28.0	101.6	100.2
12-3*	2.8	95.0	118.3	10.1	9.5	29.0	22.0	101.6	101.8
12-5*	3.0	100.0	115.0	8.6	9.2	28.0	26.0	102.0	102.0
Av. of Control Pigs		97.5	116.6	9.4	9.3	28.5	24.0	101.8	101.7
Av. of Chilled Pigs		92.5	136.6	10.8	9.5	33.7	29.5	101.8	99.5

* Control pigs - left under brooder, away from sow.

**Chilled 3 hours at 34° F.

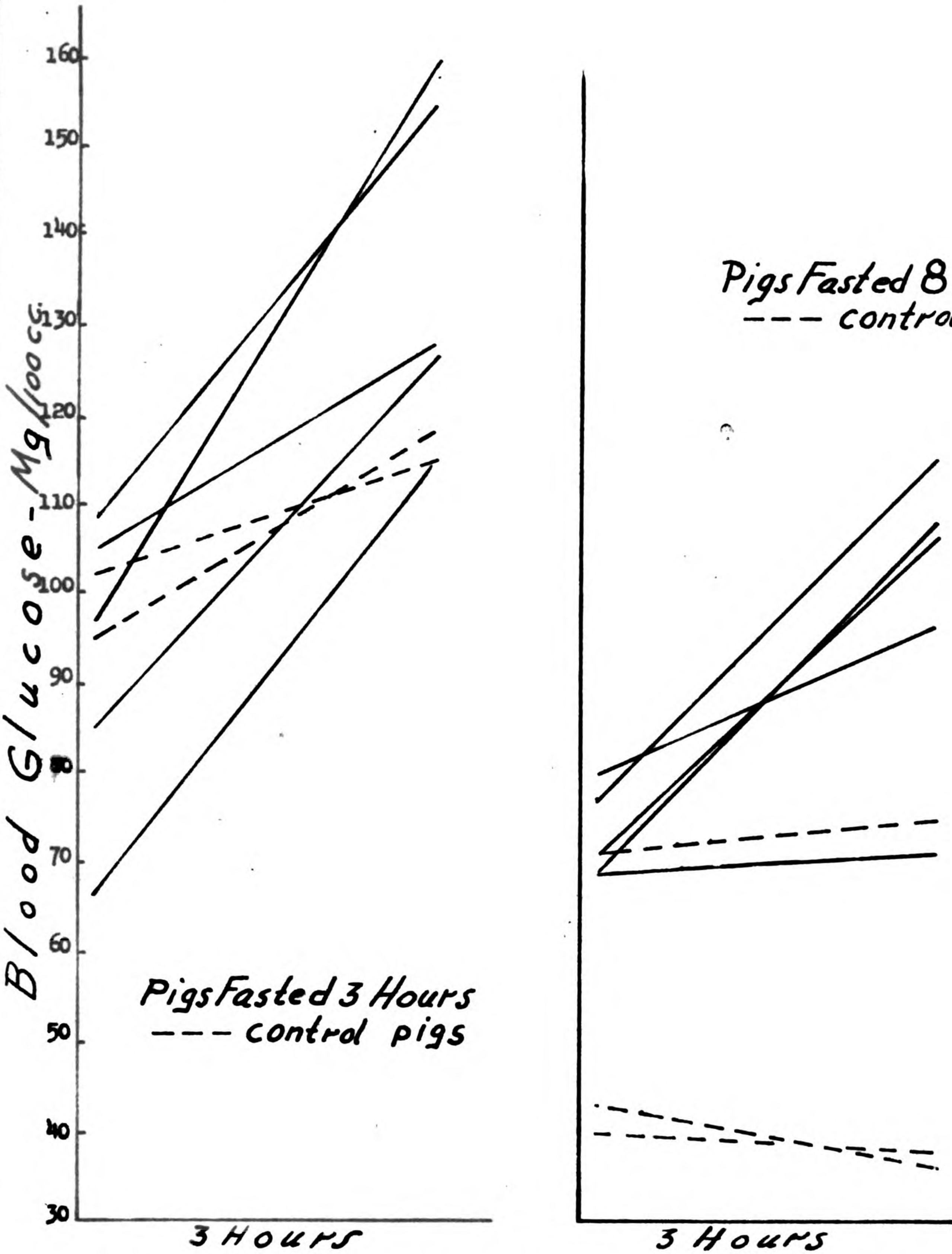
the chilled pigs increased only from 51.3 mg. to 52.3 mg. per 100 cc. blood, it can be seen from the table that pig number 15-10 exhibited a drastic drop instead of an increase. Excluding this pig, the average for the chilled group increased 13.3 mg. per 100 cc. of blood. In this group, the two control pigs dropped slightly in blood sugar, from 70.6 mg. to 64.4 mg. per 100 cc. blood. In this case, the control pigs happened to have a higher average sugar content (the reverse of the first group) but it can be seen from the table that the two groups of pigs are in about the same range. The body temperature of the chilled pigs dropped from an average of 100.6° to 93.7° F., while the controls increased slightly, from 101.5° to 102.0° F.

Reference to Table 9 reveals the wide variation in the size of these pigs. The four pigs under two pounds not only exhibited much lower drop in body temperature when chilled, but showed more varied blood sugar response. For example, pig number 15-11, weight 1.4 pounds, showed very little change in glucose, while pig number 15-10, weight 1.5 pounds, dropped from 73.3 mg. to 25.0 mg. per 100 cc. Both of these pigs dropped to 90.0° in body temperature. It should be pointed out here that at the end of two hours at 34.0° F., the three small pigs, numbers 15-11, 15-5, and 15-10, all weighing 1.5 pounds or less, had gone into a slight coma and were lying prone on the floor, too weak to rise. After being thoroughly warmed under the brooder in the farrowing pen, they were up again and nursing. See Figure 7a and b.

Pigs fasted 3 hours previous to chilling: Pigs fasted only three hours before the start of the experiment exhibited the same general trends in blood glucose response as the two other groups, Table 10. Before chilling, five pigs in this group averaged 92.5 mg., and after chilling three hours at 34° F., had increased to 136.5 mg. glucose per 100 cc. blood, or an increase of 44.0 mg. The control pigs increased 19.0 mg., which is considerably more than the control pigs on an

Figure 7a. Coma developed in one-day-old pigs chilled 2 hours at 34° F. All three pigs weighed under 1.5 pounds at birth. At the end of 2 hours they were lying in the above position, too weak to rise. These pigs were used in the blood sugar trials and were fasted 5 hours prior to the start of chilling.

Figure 7b. The same three pigs shown in 7a after warming three hours under the brooder (about 80° F.).



BLOOD GLUCOSE CHANGES IN DAY OLD PIGS AFTER CHILLING 3 HOURS AT 34° F
Note the higher beginning level and more rapid increase in blood sugar in the pigs on a 3 hour fast as compared to those on an 8 hour fast.

Figure 8

8 and 5 hour fast, both of which dropped slightly. The chilled pigs suffered a slight drop in body temperature, averaging from 101.8° to 99.5° F. The controls decreased 0.1° F. Again, as can be seen from the table, there was wide variation among the pigs and their blood sugar response when chilled. Pig number 12-2 increased from 97.5 mg. to 160.0 mg., or an increase of 62.5 mg. per 100 cc. blood, while number 12-1 increased only 22.6 mg.

Discussion:

Increase in blood sugar has been known for some time (Freund, 1913) to be a phenomena occurring when warm-blooded animals are exposed to cold.

It should be pointed out here that even with an increase in blood sugar, most of the pigs used in this experiment showed a drop in body temperature; the amount of drop depending on the size of the pig. The three small pigs (Table 9) whose body temperature dropped to 90.0° F. when chilled, had a varied response in blood sugar; one increasing, one remaining about the same, and the other decreasing. The reason for a drop of 48.3 mg. of glucose per 100 cc. blood in pig 15-10, instead of an increase, cannot be easily explained. However, Rodbard (1947) found a blood sugar drop in chicks when they were cooled sufficiently to cause a drop in body temperature. It is also assumed that the glycogen reserves are lower in a small pig and would be depleted more rapidly.

From these data it can be seen that pigs fasted 8 hours before the start of the experiment showed a lower blood sugar level before chilled and increase less than those fasted only three hours (see Figure 8). This is in agreement with the observations of Hanawalt (1947) who found the blood sugar levels in pigs to be proportioned to the length of the fasting period.

It was not possible in this experiment to study the mechanism causing an increase in blood sugar when pigs are chilled. However, Hartman (1949) states that cold is one of the most effective means of stimulating both the medulla and cortex of the adrenal gland, indicating increased adrenalin secretion. It has also been shown by Blum (1901) and later by Cannon (1924), Cori (1931), and others, that epinephrine injected into animals causes an increase in blood sugar, arising primarily from the glycogen in the liver (Mann, 1924).

The blood sugar rise shown in these pigs is apparently a defense mechanism of the body against cold. Horvath (1938) showed that normal rats respond to cold by greatly increased heat production, the caloric output per 24 hours increasing from an average of 894 to about 2500 calories per square meter. He also found that the increase in heat production on exposure to cold is less in the unilaterally adrenalectomized than in the normal rat. That the thyroid is also important in this respect was shown by Marine and Lenhart (1920) who found that epinephrine does not exert its normal calorigenic effect in the absence of the thyroid.

HEMOGLOBIN CHANGES IN CHILLED PIGS—The average hemoglobin for all pigs used in this study between the ages of one to four-days-old, was 10.2 gm. before chilling and 9.4 gm. per 100 cc. blood after chilling (Tables 7, 8, 9, and 10). For two-week-old pigs, the values were 10.2 gm. and 9.5 gm., and for three-week-old pigs 9.3 gm. and 9.2 gm. per 100 cc., before and after chilling, respectively. The values for pigs 2 to 4-days-old and 3-weeks-old are in agreement with Kernkamp (1932), Vestal et al. (1938), and McMillen and Thorp (1949). The values for two-week-old pigs remained about the same, Table 7b, which disagrees with the above authors, who found a decided drop of hemoglobin in one and two-week-old pigs, returning to normal between 3 to 6 weeks of age.

From the data reported here, chilling seems to have little, if any, effect on the hemoglobin in young pigs. However, Howie and his co-workers (1948) observed lower than normal hemoglobin values in 8-week-old pigs raised in cold environments.

SUMMARY

Body temperature development of baby pigs was studied under various conditions of environmental temperature. The effects of chilling on body temperature, growth, and blood changes in pigs ranging in age from birth to three-weeks-old, were studied.

1. The body temperature regulating mechanism in the new-born pig is not fully developed. There was a body temperature drop of 4° to 13° F. in baby pigs during the first 30 minutes after birth, the amount of drop being related to the size of the pig and the environmental temperature. The initial drop was followed by a gradual return toward normal, which in environments of 60°-75° F. was reached in about 2 days, and in environments of about freezing temperatures was reached in about 10 days.

2. Pigs 24-hours-old withstood temperatures of 34° F. with less drop in body temperature than pigs under 4-hours-old.

3. There was a significant correlation between the weight of a pig and its ability to adapt itself to its environment. Small pigs in a fasting state passed into a coma sooner when chilled than pigs of comparable size having access to the sow's milk.

4. There was little difference in growth rate of surviving pigs of comparable weight when born and raised in an environment of 25° to 35° F. and when the temperature was 65° to 75° F.

5. Blood hematocrit (cell volume) decreased when two-day-old pigs were chilled at 34° F., which is in the reverse direction for a normally functioning temperature regulating mechanism. When 10-day and three-week-old pigs were chilled, the hematocrit remained almost unchanged.

6. There was a sharp increase in blood sugar when one-day-old pigs were chilled at 34° F., indicating increased heat production. Pigs fasted 8 hours before chilling showed less glucose increase than those fasted 3 and 5 hours.

7. There was no significant change in blood hemoglobin when pigs were chilled.

LITERATURE CITED

1. Barbour, H. G.
   1912 Arch. Exp. Path. Pharm. 70: 1.

2. Barbour, H. G., and Tolstoi, E.
   1921a Role of the Nervous System in the Regulation Against Cold. Proc. Soc. Exp. Biol. and Med. 18: 184-86.

3. Barbour, H. G.
   1921b Environmental Temperature Changes and Blood Concentrations. Proc. Soc. Exp. Biol. and Med. 18: 186-188.

4. Barbour, H. G., and Tolstoi, E.
   1923 The Role of the Water Content of the Blood and Its Control by the Central Nervous System. Am. J. Physiol. 67: 378.

5. Barbour, H. G., and Aydelotte, B. F.
   1933 Am. J. Physiol. 104: 127-138.

6. Barbour, H. G.
   1941 Temperature. Its Measurement and Control in Science and Industry. Reinhold Publishing Co., N. Y. p. 436-445.

7. Blum, F.
   1901 On Adrenal Diabetics. Deut. Arch. Klin. Med., 71: 146.

8. Brody, E. B.
   1943 Am. J. Physiol. 139: 230.

9. Brody, Samuel
   1945a Bioenergetics and Growth. Reinhold Publishing Co., N. Y. p. 265.

10. Brody, Samuel
    1945b Bioenergetics and Growth. Reinhold Publishing Co., N. Y. p. 289.

11. Brody, Samuel
    1945c Bioenergetics and Growth. Reinhold Publishing Co., N. Y. p. 354.

12. Burton, A. C.
    1939 Ann. Rev. Physiol. 1: 109.

13. Cannon, W. B., McIver, M. A., and Bliss, S. W.
    1924 A Sympathetic and Adrenal Mechanism for Mobilizing Sugar in Hypoglycemia. Am. J. Physiol. 69: 46-66.

14. Cannon, W. B.
    1929 Organization and Physiological Homeostasis. Physiol. Rev., 9: 397.

15. Cannon, W. B.
    1932 The Wisdom of the Body. W. W. Norton and Co., N. Y. p. 186.

16. Cori, C. F.
1931 Mammalian Carbohydrate Metabolism. Physiol. Rev., 11: 143-252.

17. Dempsey, E. W., and Astwood, E. B.
1943 Determination of the Rate of Thyroid Hormone Secretion at Various Environmental Temperatures. Endocrinology, 32: 509-518.

18. Dukes, H. H.
1943 The Physiology of Domestic Animals. Comstock Publishing Co., Inc., Ithaca, N. Y. p. 474.

19. Freund, H., and Strasmann, R.
1912 Arch. Exp. Path. Pharmak. 69: 12.

20. Freund, H., and Marchand, F.
1931 Arch. Exper. Path. Pharm. XXIII. 276.

21. Glaubach, S., and Pick, E. P.
1933 Arch. Exp. Path. Pharmak. 173: 571-9.

22. Giaja, J., and Geliner, S.
1933 Arch. Intern. Physiol. 37: 20.

23. Hanawalt, V. M., and Samson, Jesse
1947 Studies on Baby Pig Mortality. The Relationship Between Age and Time of Onset of Acute Hypoglycemia in Fasting New-Born Pigs. Am. J. Vet. Res. 8: 235-243.

24. Harrlass, H.
1941 Landu Fb. 91: 147-197.

25. Hartman, F. A., and Brownell, K. A.
1949 The Adrenal Gland. Lea and Febiger, Philadelphia, Pa. p. 122.

26. Heitman, H., and Hughes, E. H.
1949 Effects of Air Temperature and Relative Humidity on Physiological Well-Being of Swine. J. An. Sci., 8: 171.

27. Horvath, S. M., Hitchock, F. A., and Hartman, F. A.
1938 Response to Cold After Reduction in Adrenal Tissue. Am. J. Physiol. 121: 178-184.

28. Horvath, S. M., Folk, G. E., Craig, F. N., and Fleischmann, W.
1948 Survival Time of Various Warm-Blooded Animals in Extreme Cold. Science, 107: 171.

29. Howie, J. W., Biggar, W. A., Thomson, W., and Cook, R.
1948 An Experimental Study of Pig Rearing. J. Agr'l. Sci., 39: 111-118.

30. Kelley, M. A. R., and Rupel, I. W.
1937 Relation of Stable Environment to Milk Production. U.S. Dept. Agr. Tech. Bul. 591. 60 pp.

31. Kernkamp, H. C. H.
1932 Univ. Minn. Tech. Bul. 86.

32. Kleiber, M., and Winchester, C. F.
1933 Temperature Regulation in Baby Chicks. Proc. Soc. Exp. Biol. Med. 31: 158.

33. Kleitman, N., Titelbaum, S., and Hoffman, H.
1937 Am. J. Physiol., 119: 48.

34. Korenchevsky, V.
1926 Influence of the Removal of the Thyroid Gland on the Regulation of Body Temperature. J. Path. and Bact. 29: 461.

35. Leblond, C. P., Gross, J., Peacock, W., and Evans, R. D.
1943 Metabolism of Radioiodine in the Thyroids of Rats Exposed to High or Low Temperatures. Am. J. Physiolo. 140: 671.

36. Lozinsky, Ezra
1923 The Effects of Dry and Moist Heat Upon the Body Temperature and Blood Concentration of Dogs. Am. J. Physiol. 67: 388.

37. Madsen, L. L., Earle, I. P., Heemstra, L. C., and Miller, C. O.
1944 Acute Uremia Associated with "Uric Acid Infarcts" in the Kidneys of Baby Pigs. Am. J. Vet. Res. 5: 262.

38. Mann, F. C., and Magath, T. B.
1924 The Effect of Total Extirpation of the Liver. Ergebnisse Physiol. 23: 212.

39. Marine, D., and Lenhart, C. H.
1920 Effect of Subcutaneous Injections of Adrenalin on Normal and Thyroidectomized Rabbits. Am. J. Physiol. 54: 248-260.

40. McMillen, W. N., and Thorp, F. Jr.
1949 Michigan Agricultural Experiment Station. Unpublished Data.

41. Ranson, S. W.
1940 The Hypothalamus. Williams & Wilkins Co. p. 342.

42. Reineke, E. P., and Turner, W. C.
1945 Seasonal Rhythm in the Thyroid Hormone Secretion of the Chick. Poultry Science. 24: 499-504.

43. Regan, W. M., and Richardson, G. A.
1938 Reactions of the Dairy Cow to Changes in Environmental Temperature. Jour. Dairy Sci. 21: 73-79.

44. Rhoad, Albert O.
1935 The Dairy Cow in the Tropics. Am. Soc. Animal Prod. Proc. 28: 212-214.

45. Riddle, O., and Fisher, W. S.
1925 Seasonal Variation of Thyroid Size in Pigeons. Am. J. Physiol. 62: 464.

46. Rodbard, S.
1947 Relationship Between Body Temperature and Blood Sugar in the Chicken. Am. J. Physiol. 150: 67-9.

47. Vestal, C. M., and Doyle, L. P.
1938 Purdue Univ. Bul. No. 426.

[redacted]Y [redacted]