THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Carl Fountain Huffman final oral examination for the degree of

Master of Science

We recommend that the degree of

Master of Science

be conferred upon the candidate.

O. H. Eckles
Chairman

Leroy D. Palmer

F. B. Kingsbury

Date _____

10-20 5M

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Carl Fountain Huffman for the degree of Master of Science They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

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# MILK AS THE SOLE DIET FOR CALVES

by

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TABLE OF CONTENTS

# INTRODUCTION

Milk, the secretion of the mammary gland, has long been considered the food best adapted to the complete nourishment of young mammalia. It is the sole diet of all mammals during the early period of infancy, and is regarded as an excellent staple in the diet of the adult human, especially in the case of invalids.

In recent years many investigations have been made concerning the nutritive value of milk, and it has measured up to all expected standards. In fact it is often referred to as the only perfect food.

The proteins, fats and carbohydrates are present in the proportions that are best suited for the growth of young animals. It has been shown conclusively that milk contains an adequate protein, having all the amino acids necessary for life, growth and physiological development of animals.

It has also been demonstrated that whole milk contains sufficient fat soluble "A", water soluble "B" and the antiscorbutic vitamine to insure complete physiological functioning.

Milk has also been shown to contain sufficient ash to meet the needs of the growing animal, although the quality may not be best suited to the requirements of the animals.

Even though the nutritive value of milk is very high, there are limitations to its use - limitations which may not be in the milk itself, but in the class of animals to which it is fed. Davenport pointed out twenty five years ago that calves can not be grown from birth to maturity on milk alone. Also many instances are known where calves were fed heavily on milk in an endeavor to speed up growth, resulting in a physiological failure, which in all probability was

due to some deficiency in the milk as a food for older calves.

This deficiency has been attributed to a lack of bulk, which is furnished ordinarily in the form of roughage. It has been assumed that calves after they reach a certain age need roughage for proper physiological functioning. Before the domestication of cattle, milk production was merely sufficient for the offspring during the early post-natal development. As the food requirement became greater, the calf was forced to consume other food which was usually available in the form of roughage, which overcame the deficiency of milk. However, in the light of our present knowledge of vitamines and mineral feeding, the possibility of either a vitamine or a mineral deficiency is suggested. Possibly roughage contains a factor other than bulk, which makes up the deficiency of milk as the sole diet for calves.

The requirement of calves for a certain factor, may also increase with age, which may account for their failure to grow from birth to maturity on an exclusive milk diet.

In 1918, McCandlish published his results corroborating the earlier observation of Davenport. In view of the development of the vitamine hypothesis, it seemed possible that the deficiency of milk was one of vitamine rather than of roughage as was suggested by these investigators.

Preliminary experiments to determine this point were started at the Minnesota Experiment Station in 1921. The results observed in these experiments will be discussed later. The work of the present author has been to continue this study of the subject for the purpose of determining in so far as possible the nature of this deficiency of milk. The question of the mineral supply is involved as well as that of the vitamines.

## GENERAL DISCUSSION AND REVIEW OF LITERATURE

Milk has often been called the only perfect food, and statements are made to the effect that it supplies everything needed for a complete ration. A review of the literature dealing with the results of using milk as the sole diet of some of the domestic animals indicates that either milk alone is deficient in some respect as a food, or that the digestive systems of those animals are not adapted to its use as the sole diet from birth to maturity.

Osborne and Mendel (1) state that in numerous experiments, milk has proven an adequate food both for growth and maintenance. Young rats fed on a diet consisting of 60 % milk, 12 % starch, and 28 % lard not only have grown from infancy to maturity, but have also given birth to litters of normal young, which in turn have thriven on diets precisely like that of their parents. They concluded that milk foods contain all that is essentially necessary for both growth and maintenance.

McCollum (2) fed a sow successfully for an entire year on whole milk, and later, on a mixture of skim milk and whole milk, without affecting her reproduction. He concluded that milk alone will support a pig.

On the other hand Gibson and Conception (3) found that puppies and pigs even while growing developed symptoms of peripheral nerve degeneration when milk whether fresh or heated formed their sole diet.

Herter (4) fed a pig on skim milk alone for fifty-one weeks. At the end of thirty weeks, it showed a weakened condition in the hind legs, and after fifty weeks it was unable to stand. The muscles

were flabby, but from all appearances there was no indication of wasting. On the contrary, the legs were puffy in appearance. The breathing became rapid and labored, a few days before death. Post-mortem revealed enlarged pancreas, kidneys, adrenals, and heart, also a hemorrhagic condition in the medulla. The knee joints contained bloody and viscid synovial fluid. The bones of the skull were porous and brittle, and distinctly thinner than those of a normal animal the same size. A majority of the muscles showed marked reduction in size.

Another pig was fed skim milk, and a carbohydrate to compensate for the fat lacking in the milk. This pig showed practically the same symptoms and the post-mortem revealed the same condition as in the case of the pig fed skim milk alone.

A third pig was fed for sixty-six weeks on an unlimited amount of skim milk which resulted in the same peculiarities as the other pigs.

Davenport of Illinois (5) was the first to attempt to raise calves from birth to maturity on milk alone. A calf was placed on a diet of skim milk at six days of age. By the time it was six months old, it was getting as much as fifty pounds of skim milk a day, but at this age it lost its ravenous appetite and no longer appeared restless as it had previously appeared. After seven months on an exclusive skim milk diet this calf became stiff and finally refused to get up and take its milk. The eleven days previous it had gained thirty six pounds. Hay and straw were fed and three hours later the calf was ruminating for the first time in its life. It also exhibited a brighter eye and a more contented expression. A few hours later the calf was up and walking. A ration consisting of hay, straw, grain, and milk was then fed for three months and at the end of this time it was in every respect well, hearty and growing, and as active

as any calf in the barn.

Another calf was fed on whole milk alone for five months. At twenty-two weeks of age, symptoms of starvation appeared - increased appetite and an erormous consumption of food that seemed not to satisfy. Hay was given and rumination began in five and one-half hours. A ration of grain, hay and milk brought it back to normal.

Davenport concluded from his experiments that ruminants need roughage after they reach a certain age.

McCandlish (6) attempted to raise two calves on whole milk alone. No roughage, grain or water was offered either of the calves and at first no salt was given; one calf was given salt ad libitum after thirty days of age, and the other after seventy days of age. Shavings were used at first for bedding, but they were later replaced by sand as the calves showed a tendency to eat the shavings. The calves made fairly good gains in weight until about three months of age, after which they did not thrive, but continued to gain in weight slowly for another thirty days, after which their live weight gradually decreased until death. The calves on whole milk alone doubled their live weight, while normal herd calves which were used as a check attained weights four times as great. The heights of the whole milk calves were about normal. Nevertheless they became emaciated and unthrifty in appearance. Their coats were long, the hair fell out freely and there were also sores on the body. The calves came down on their pasterns, could not stand properly and walked with a stiff gait. These calves also had convulsions which were apparent at three to four months of age and continued at irregular intervals until three weeks before their death. These fits were all similar and frequently started with no apparent reason and could almost always be induced by leading the animals around for a few minutes.

The animals would fall down and bellow as if in pain. The jaws would stick open and the legs become rigid, muscles tense and hard; respiration slowed, and in severe attacks entirely stopped. When respiration did not stop the animal would recover in a few minutes. When breathing ceased, artificial breathing restored the calves.

Post-mortem of one calf showed that the bones were very flexible as if insufficient ash was present; the leg bones could be bent fairly easily and the ribs had a very thin coating of hard material with a soft core. The organs of digestion were practically normal. The bones of the other calf appeared to be in fairly good condition and the stomach also appeared normal.

McCandlish concluded from his experiment that the inability of milk to properly nourish older calves is probably not due to any defect in the quality or quantity of the nutrients it supplies but is probably due to an insufficient amount of dry matter which should have been provided in the form of roughage. The digestive tract of a ruminant is large and capacious, and before digestion can take place, bulky feeds must be present to distend the digestive organs, stimulate peristalsis, separate the particles of more concentrated feeds and to allow of their being properly mixed with, and acted on by the digestive fluids. Milk not being a bulky food will not induce the digestive tract to function properly in older ruminants. Where digestion is retarded or hindered, the materials not completely acted upon by the digestive juices remain in the alimentary canal and undergo putrefactive changes. The products of such changes are toxic when absorbed from the alimentary canal can produce autointoxication with symptoms similar to those found in these calves.

Hughes and Cave (7) at the Kansas station fed two calves whole milk alone the first five months and at this point changed to

a mixture of whole and skim milk. These calves were muzzled and given free access to water at all times. These calves were in fair condition until about one year of age when they showed stiffness and swollen joints, followed in one case by death. The other animal was fed two ounces of bone ash, which caused the stiffness and swollen joints to disappear. One calf was placed on the experiment November 23, 1920 and the other December 7, 1920, which caused them to reach the stage when the whole milk causes complications during the spring when they received plenty of exercise and sunlight, and probably drank more water; which may be the reason why these calves failed to come down with convulsions.

Davenport (5) attempted to grow cattle without coarse feed other than milk alone. In his first experiment a calf was started on whole milk, and grain was given at an early age, nevertheless there appeared a phenominal appetite for bulky foods and indications of an unsatisfied appetite. The calf ate shavings which were used for bedding, chewed lumber, ropes, etc. A ration consisting of one-half corn and one-half oats did not satisfy the desire for coarse material. In its eagerness for something more different in the way of food, earth was eaten freely if available; but as this habit is a normal one with horses, and as all cattle evince an abnormal appetite for anything that may be chewed, the calf was closely watched to see whether these peculiarities might not ultimately disappear and the animal settle down to its regular food, and be satisfied with a non-herbiverous diet, which it never did. At four months of age this calf's joints commenced to swell and the legs became stiff. Later it had spells of walking by reeling motions although at other times it played and acted normal. At about five months of age, there was an evident disturbance of the nervous centers, and though the calf

never missed a meal or suffered from disturbed digestion it was evident that it could no longer live. The calf was then killed, and the post-mortem revealed nothing peculiar in the development of the internal organs.

Another calf was fed an exclusive grain ration after it was three months of age. Previous to this time, it received a diet consisting of milk with a little grain. Its appetite improved and its appearance became brighter on a ration of bran and whole oats, but after a 47 pound gain in one week, and almost without warning, it died.

In these experiments of Davenport both from feeding grain and milk alone, there was a sudden and extreme increase in weight just before the collapse. The calves also showed uniform symptoms - a ravenous appetite followed by enlargement and stiffness of the joints, spells of dizziness and difficult locomotion, all followed by periods of relief, and finally by a settled indifference to food. This condition could be removed temporarily by any change of food, but permanently by coarse food only, which never failed to effect a restoration to normal conditions.

Davenport concluded from these experiments that whether food be insufficient or imperfectly adapted in quality to the needs of the animal, the result is the same, defective nutrition which is in no sense different from starvation. In other words, ruminants need coarse feed in their ration after they reach a certain age.

On the other hand it is reported that ruminants have been fed successfully on a ration lacking in bulk. In 1784 Miller (8) reported that he had maintained dry cows weighing about 900 pounds for eight weeks in the winter by feeding not more than six pounds of finely ground corn meal daily. At first the cows were restless, but

they soon quieted down and rumination ceased. The cows showed no signs of suffering or unrest and were more quiet than cows getting four to five pounds of hay daily.

Eckles and Wilbur (9) fed a calf on whole milk and calcium carbonate for eight months, at which time it was normal in every way. This work also indicates that calves do not need roughage to grow from birth to maturity, but the cause of convulsions and eventual death may be due to something else.

## General Discussion Of The Probable Cause Of Convulsions In Calves Fed Whole Milk Alone

The work of Davenport (5), McCandlish (6), and Eckles and Wilbur (9) show that calves come down with convulsions and die when milk is their sole diet. Davenport and McCandlish attributed the failure of milk as the sole diet for calves to a lack of roughage.

If the lack of roughage is the cause of convulsions in calves fed whole milk alone, our problem would be a simple one, but the results of Hughes and Cave (7) and those of Eckles and Wilbur indicate that it is not a question of roughage. Eckles and Wilbur first thought that the convulsions in calves fed an exclusive diet of whole milk might be due to a vitamine deficiency. The addition to the ration of yeast to supply water soluble "B" and orange juice to furnish water soluble "C" did not relieve the condition. However, they were able to cure and prevent the occurrence of convulsions by feeding calcium carbonate with the milk diet.

These results suggest the possibility that the convulsions may be due to a lack of calcium in the diet. In the experiment of Hughes and Cave (7) the calves did not come down with convulsions due possibly to the fact that the critical period came in the summer, at which time they were getting more exercise and drinking more water.

As the water supply at the Kansas station is very high in calcium, the more water consumed the more calcium taken into the digestive tract, which no doubt helped to furnish the calcium needed in the body.

The idea that the lack of calcium in the diet may produce convulsions suggests the possibility that the calves fed on whole milk alone develop either acidosis or some form of rickets.

## Acidosis

Eckles and Wilbur (9) found that convulsions could be either prevented or cured in whole milk calves by the addition of calcium carbonate. It was suggested that probably the calcium carbonate overcame a condition of acidosis by increasing the alkaline reserve of the blood.

The American Illustrated Medical Dictionary (10) defines acidosis as increased acidity, or rather a decreased alkalinity of the blood; depletion of the alkaline reserve of the body, resulting in acid intoxication.

According to Frothingham (11) acidosis as used in medicine is applied to a variety of conditions in which there are substances which readily give rise to bases. The impoverishment may be due to:

1. Faulty absorption of bases.
2. An unusual loss of bases from the body.
3. Their neutralization by abnormal amounts of acid.

The increase of the amount of acid in the body may be due to:

1. Production of abnormal acid.
2. Over production of usual body acid.
3. An accumulation of normal acids due to failure in excretion.

According to Tribbles (12) acidosis is especially liable to follow a strict diabetic or carbohydrate free diet, insufficiency of food or excess fat or protein. Some infants can not digest food containing more than one per cent of fat, as heavy fat feeding may give rise to indigestion, fat diarrhoea, acidosis and convulsions. Inability to digest fats results in a weakened vitality, which causes a lessening of the oxidation processes in the tissue. This leads to the formation of oxybutyric acid which causes an acid intoxication known as acidosis.

Cammidge (13) defined acidosis as an accumulation of acid products of metabolism in the body owing to an excessive production, or to defective elimination, or both together. It may be considered from the standpoint of a deficiency of bases due to an excessive loss or to an inadequate absorption of bases from the intestines to meet the ordinary requirements of the body. An elimination of calcium, magnesium, and ammonia is also usually found in acidosis. Sodium, potassium, calcium and magnesium are present in all tissues and fluids while ammonia can be formed when necessary. The smooth and efficient working of the nervous tissue is dependent on its being supplied with a fluid containing a certain concentration and quantitative proportion of calcium to magnesium. Withdrawal of bases from the tissues may consequently be expected to show itself by increased functial disturbances in the nervous system. The hydrogen-ion concentration of the blood can only vary within an exceedingly narrow zone without producing serious effects. If available alkalies in the blood are not sufficient to neutralize the acids formed, bases are withdrawn from the tissues for this purpose, and fresh sources of alkali are tapped in the form of ammonia which is diverted from its normal destiny of urea formation. Ammonia formation appears to be a mechanism especially

concerned with the maintenance of a normal equilibrium between the hydrogen and the hydroxylions in the blood. Cammidge concluded that base forming foods should exceed acid forming foods in the diet.

Steenbock, Nelson and Hart (14) observed that where a calf was changed from a high acid - low nitrogen ration to a milk diet, there was a marked increase in the urinary acidity which was contrary to what might be expected. Accompanying this, there was an almost complete absence of calcium in the urine, but a large excretion of phosphorous. When the calf received a ration consisting of straw and starch, the urinary phosphorous and calcium were rather low, but they were considerably increased when the calf was changed to a straw-starch-acid diet. The fact that the urinary calcium was not increased by raising the acid intake from 200 cc. to 300 cc. of N HCl supports the idea that urinary calcium and phosphorus in these periods were mainly, if not entirely, coming from the ingested straw. If it had its origin in the bones, a progressive rise in urinary calcium with increased acid intake would have been expected. When, however, 400 cc. of acid were given the calf, there was a marked increase in urinary calcium excretion. Since there was no rise in urinary phosphorus in the high acid intake, it can be inferred that the extra calcium was coming from the calcium carbonate - calcium phosphate complex of the bones. In other words, not until there was a high intake of acid, were the bones drawn upon for bases, and then only the calcium carbonate portion. The marked rise in urinary acidity accompanying the milk diet, with the disappearance of calcium from the urine, is possibly due to the rapid storage of calcium on cessation of a high acid diet.

According to Marriott and Howland (15) the evidence of acidosis is a diminished alkaline reserve. They explain acidosis

by saying that the kidneys fail to play their part - the excretion of acid substances already formed. The regulation of the acid - base equilibrium depends on the ability of the kidneys to excrete acid phosphate. They also found in most cases studied, a marked reduction of the calcium of the serum. What influence this low calcium content may have on the production of such symptoms as convulsions and hemorrhages can only be guessed. The low calcium content is due to the excess of phosphate in the plasma. It has been shown that phosphates administered in any form cause a loss of calcium, chiefly in the feces. The administration of calcium leads to an increased elimination of phosphate in the feces.

Another theory as to the cause of acidosis is that of Martin Fischer (16) who found acid intoxication with edema of the brain, which if not treated produces a headache and drowsiness, followed by stupor and coma. Fischer states that no patient recovers who secretes urine that remains persistently acid to methyl red. In acid intoxication, headache and vomiting are followed by convulsions. The administration of sodium bicarbonate and magnesium sulfate in several small doses cures edema of the brain. When the nervous tissue becomes slightly acid due to acid intoxication, water is taken up and these salts bring about a cure by dehydrating the brain. Fischer was able to bring about a cure of convulsions by the injection of 1800 cc. of the following mixture - sodium bicarbonate (8.4 grams) sodium chloride (28 grams) and enough distilled water to make 2000 cc. He found calcium a more powerful dehydrant than magnesium, and magnesium more so than sodium. A sulfate is also more powerful than an acetate, iodide or bromide, and these in turn are more active than a chloride. Magnesium is sixty times more powerful a dehydrant than sodium.

Forbes, Halverson and Schulz (17) working with two pigs

found that the addition of calcium carbonate to a cereal ration increased the alkaline reserve of the blood plasma 10.1 % and 10.8 % respectively, above that which prevailed during the feeding of the cereal ration alone. By the substitution of precipitated bone phosphate for calcium carbonate, the alkaline reserve was reduced 14.8 % and 15.4 %. They concluded that the alkaline reserve of the blood plasma of swine may be significiently increased by feeding calcium carbonate, or decreased by the feeding of potentially acid calcium phosphate.

According to Blatherwick (18) cows normally excrete a strong alkaline urine which is loaded with carbonates due to the diet which is strongly basic. On the other hand calves which consume milk, an approximately neutral food, commonly excrete urine that is neutral or amphoteric to litmus. Judging from these facts, it would be expected that calves would have a smaller alkaline reserve than cows, but such is not the case. The average carbon dioxide capacity of the blood plasma of seven calves ranging from two days to fourteen days of age was 73.0 % with a minimum of 63.3 % and a maximum of 80.6 %. The alkali reserve for a month old calf was 61.4 %, which is practically identical with that of mature cows, which is taken at 61.5 %.

The results of this work, and also that of Meigs, Blatherwick and Cary (19) show that the plasma of calves is characterized by a high content of calcium and inorganic phosphorus. The calcium soon begins to decrease toward the adult level, but the phosphate gains in amount until the highest point is reached at the age of about six months.

Van Slyke and Cullen (20) state that unusually high values for plasma carbon dioxide capacities are sometimes observed after the subject has partaken of an alkaline diet.

Schloss and Harrington (21) were able to increase the plasma carbon dioxide combining power of infants' blood by appropriate changes in the diet.

However, on the other hand McClendon, Von Meysenburg, Engstrand and King (22) were unable to produce any change in the alkaline reserve of man by varying the diet.

Investigators are fairly well agreed that the alkaline reserve of the blood can be altered by feeding. There is a possibility that calves fed on whole milk alone develop a condition of acidosis which is the cause of the convulsions.

However, the work of Eckles and Wilbur (9) where convulsions were cured and prevented by feeding Ca $Co_3$ suggests the possibility of rickets in the calves fed whole milk alone, since rickets is attributed by some authorities to the lack of calcium assimilation.

McCandlish (6) found faulty bone development in one of his calves which died due to an exclusive whole milk diet which is a further indication that a rachitic condition may exist in calves fed whole milk alone.

## Rickets

Rickets, or Rachitis is a disease of infancy and early childhood, characterized by alterations in the bony skeleton and by impaired nutrition. Rickets was known to writers in the early ages, but was confused with other skeletal deformities. Glisson in 1650 published the first accurate description of the condition. The disease occurs most frequently among children in the crowded sections of the city, inhabited by the lower classes. Rickets occur on all kinds of diets, where the infants are fed cows' milk and where they are fed mothers' milk, but it is more prevalent among artificially fed infants, and is especially common among children on artificial diets containing

large quantities of carbohydrates and small amounts of fat.

Rickets is primarily a disease of the bones, although it must be regarded as a general disturbance of metabolism. Rickety children show a weak muscle tonus and perspire profusely, particularily on the scalp. Early stages of rickets are characterized by restlessness during the night, craniotabes (thinning of spots in the infantile skull) and beading of the ribs. The latter is an early and valuable symptom, consisting of a row of nodules produced at the costa-chondral junctions. Later, if the disease becomes severe, bone deformations occur. The deformities are due to rachitic curvature of the bones, and uneven enlargement of various portions of the bones.

The use of the roentgen ray has enabled clinicians to obtain an objective criterion for diagnosing rickets. The uncalcified condition of the bones and cartilege can be determined by the roentgen ray.

Authorities are not agreed as to the nature of the causitive agent in rickets. Some investigators attribute it to a lack of calcium salts in the blood, or imperfect absorption of the lime salts from the intestine due to the lack of the anti-rachitic factor. Others maintain that rickets is due to the lack of phosphorus, either in the diet, or lack of proper absorption. Still others associate the disease with unsuitable hygienic surroundings and others attribute it to a lack of sunlight.

The Relation of Hygiene, Exercise, and Sunlight to Rickets. For centuries there has been a strong belief that hygiene is the etiological factor in rickets. At one time the popular theory was that of Kassowitz (23) who believed that rickets is due to breathing the noxious gases of badly ventilated rooms.

Margaret Ferguson (24) regarded inadequate air and exercise

as more important in producing rickets than a deficient diet.

Gossage (25) states that rickets is more prevalent in bad hygienic surroundings, lack of fresh air and sunshine, and is more frequent in winter. Among animals, those confined to cages become rickety, while the disease is unknown when they run wild. Gossage suggested that the absence of sunshine, fresh air and exercise might affect the absorption and assimilation of foods. However, the Eskimo infants, who for six months of the year are confined to cramped dwellings, with no sunshine and no fresh air, do not develop rickets. These infants are breast fed for nearly two years.

According to Jacobohn (26) associated with inadequate foods which go with rickets, are usually found unsuitable clothing, lack of bathing and cleanliness, poor heating and ventilation, deficient sunlight and unsanitary conditions.

Paton, Findley and Watson (27) kept one lot of pups in the country and one in the laboratory. Altho those in the country had a smaller amount of milk fat than those kept in the laboratory, they remained free from rickets, while those in the laboratory did not, which indicates that milk fat does not contain the anti-rachitic factor, and that exercise may prevent rickets. While Mellanby (28) concludes that exercise plays only a subsidiary part in the development of rickets.

Working with human infants Hess and Unger (29) found that rickets occurred occasionally on every food without exception; on a diet containing a large amount of milk and therefore rich in fat, and on a diet lacking in fat and fat soluble "A"; on raw or pasteurized milk. It has been noted on fluid milk, human milk, whole milk and cereal; dried milk, condensed milk, protein milk, and dried milk, cereal and orange juice. The treatment of these cases of rickets by

sunlight caused marked improvement in every case as evidenced by the calcification of the epiphyses. The alteration resembled that which followed the administration of cod liver oil. In one case, calcification of the epiphysis of both wrists was evident, when as yet but one arm had been exposed. The action of the sun's rays is systemic and not local. The diet was not altered during the treatment.

Recently, Huldschinsky (30) has shown that infantile rickets can be cured by the rays of mercury vapor quartz lamp.

Hess and Unger (31) were also able to protect rats from rickets by sunlight on a diet deficient in phosphate, and when the blood phosphate was low. These investigators have been employing the direct sunlight as a therapeutic measure since 1920.

The seasonal factor in rickets is largely climatic and is due almost entirely to a lack of sunlight. Rickets cannot be prevented from developing in the winter by feeding the milk of cows that have been pasture fed. Moreover rickets is far less frequent in a mild winter than in a severe one.

There is no doubt, however, that rickets is not only hygienic, but also a dietetic disorder, as rats fed an ideal diet do not develop rickets when kept in the dark. However, a large proportion of the infants in our large cities do not receive a diet which, from a chemical standpoint is correctly constituted, and these infants need light to protect them from rickets.

The amount of light required to prevent or cure rickets depends on the diet, rate of growth and the pigment of the skin. More light was required for protection where the diet was poor. Also, more light is required to prevent and cure rickets where the rate of growth is rapid. The potency of light is also affected by the intensity of pigmentation of the skin. Black rats developed rickets

sooner than white ones, other factors being equal. Negro babies require a greater degree of light rays than do white infants. That they possess no racial predisposition to rickets is evidenced by their freedom from this disorder in their native land.

These clinical results, which indicate the importance of hygiene in relation to rickets, have been substantiated by the work of Powers and Parks, and McCollum and Shipley (32) who found that when rats fed on a rickets-producing diet can be regularily prevented from developing this disorder by short and frequent exposures to the sun's rays.

From the review of literature, it appears that light rays play a part in the prevention and cure of rickets. The work of Hughes and Cave (7) indicates that exercise and sunlight may prevent calves fed on whole milk alone from coming down with characteristic convulsions which suggests the possibility that the convulsions, usually resulting from an exclusive milk diet may be associated with some form of rickets.

The Relation of Fat in the Diet to Rickets. Rickets is thought by some investigators to be due to a lack of proper calcium absorption. It was suggested that possibly fat feeding carried the calcium ingested, into the feces as insoluble soaps, thus producing a calcium loss, resulting in a rachitic condition. As milk is high in per cent of fat, it was thought that convulsions which calves develop when fed on it exclusively, might be a form of rickets caused by a loss of calcium in the feces as insoluble calcium soaps.

Steintz (33) has shown that in infants, fat diet may lead to a negative balance of the alkali salts. On a diet rich in cream, the absorption of calcium dropped from 76 % to 34 % of the total intake. Rothberg (34) also found that a nourishment rich in fat gave

a negative calcium balance.

Given (35) states that the frequent conception of the digestion and utilization of fats and other comparable esters of fatty acids, would lead one to expect that if they are hydrolysed in the normally functioning alimentary tract, the resulting fatty acid will either be absorbed promptly, or excreted as insoluble soap in the feces. The extent to which absorption occurs may therefore depend not only upon the digestion of the esters, but also upon the degree to which the alkali earths are simultaneously present in the intestines to render the fatty acids insoluble and unutilizable. Conversely the loss of alkali earths thru the bowels may likewise be promoted by the presence of large quantities of fatty acids. His results show that when fat utilization was poor - the loss of calcium was proportionally large, and he concluded that the poor utilization of fats or fatty acids may increase with the excretion of lime in the feces and prevent the storage of calcium even when the calcium intake is comparatively abundant.

It is a fact recognized by pediatrists that the digestion and absorption of fats is probably the source of a greater part of the troubles encountered with bottle fed infants who receive cows milk in some modification.

Boworth, Bowditch and Giblin (36) found that the calcium metabolism of bottle fed infants, as measured by the calcium eliminated in the urine, was seldom greater and often less, than that found in breast fed infants, most of the calcium being eliminated in the feces as insoluble calcium phosphate and calcium soaps. Calcium palmitate was the soap present in the largest amount in the stools from bottle fed infants. The soaps in the stools were almost entirely insoluble. While this method of eliminating the excess calcium

present in cow's milk, is, in one way, a protection to the infant, in that it prevents the calcium from entering the body fluids and tissues in organic combination subsequently to set up a toxic condition. Calcium phosphate was found practically inactive. Where the foods contained calcium caseinate, and calcium caseinate plus calcium acetate, the urine became phosphorus free, all the phosphorus in the food being precipitated in the intestine as calcium phosphate and excreted in the feces. The presence of large quantities of calcium soaps in the stools from bottle-fed infants receiving cow's milk, is one of the striking abnormalities noticed when a comparison is made between the analysis of such stools and those from breast fed infants. Since these soaps are insoluble they cannot act as suppository in a manner similar to the sodium and potassium soaps, and as a matter of fact, these insoluble calcium soaps in the feces often cause severe constipation, which is the starting point of the complications. Constipatory effects were not obtained when fat up to three per cent was fed, where the calcium had been removed from the milk. These investigators concluded that cows milk is the natural food for calves and is too rich in calcium for infants. The excess calcium unites with the fat, forming insoluble calcium soaps which produce constipation.

Schabad (37) demonstrated that in rachitic infants cod liver oil promotes the absorption and retention of calcium, but that the other fats very frequently produce fat constipation in which calcium is withdrawn from the system.

According to Hall (38) overfeeding of milk to infants is a fat overfeeding as shown by the fact that the bowel movements are composed largely of insoluble salts of fatty acids, that is, soaps. This disturbance of metabolism is probably an acidosis due to the withdrawal of alkalis from the body to unite with the fatty acids of

the intestines. Fat overfeeding produces rickets, as indicated by a slight evidence of rickets in all the babies that are artificially fed, and in many on good breast feeding.

Howie (39) reported a high fat content of the feces of calves on the third day after birth. This fat in the feces was accompanied by a fairly high percentage of soap which was chiefly in the form of calcium stearate.

On the other hand, Holt, Courtney and Fales (40) showed that diluted cows milk does not cause high loss of fat in the feces. In a group of thirty one children, nineteen received calcium to the extent of over a gram of calcium oxide daily. Of these, only six had as much as two grams of fat as soap in the daily stools. All but one were utilizing over 85 % of the ingested fat, while four were absorbing more than 95 % of fat ingested.

Table showing fat retention and fat excretion with high calcium intake:

| Gm. CaO intake | % fat retained | Grs. of fat excreted |
|---|---|---|
| 1.89 | 95.8 | 0.79 |
| 1.66 | 89.4 | 1.68 |
| 1.50 | 93.2 | 1.12 |
| 1.47 | 87.7 | 0.79 |
| 1.41 | 87.1 | 1.76 |
| 1.39 | 95.5 | 0.99 |

The maximum output in the feces of calcium bound as soaps in these observations was about 0.18 grams. Thus it is evident that the calcium which goes to form the stools is only a small part of the calcium intake. The loss of fat in the feces is seldom important. They concluded from these investigations that infants fed on simple dilutions of cows' milk retain enough fat; and that a high calcium

intake does not mean a big fat loss while a great reduction in the calcium of the diet of infants may be attended with considerable risk.

In a later work these investigators (41) found that the average absorption of CaO by healthy infants taking modifications of cows' milk was 0.09 grams per kilogram of body weight. The excretion and absorption of calcium were in general dependent on the amount of calcium intake. From 35 to 55 % of the calcium intake was absorbed. The best absorption of calcium was obtained when the blood contained from 0.04 to 0.060 grams of CaO for every gram of fat, and when at the same time the fat intake was not less than 4.0 grams per kilogram of body weight. An excessive calcium intake apparently did not increase the calcium absorption, the excess being excreted. When the intake of CaO was very low, less than 0.10 gm. per kilo of body weight, the absorption of CaO was less than the normal calcium requirement of the body.

They also found that the relation of calcium excretion to soap excretion was not constant. The excretion of calcium was directly proportional to the calcium intake. The constipated stools, which contained more soap than normal stools, with the lowest average soap content, showed the same content of calcium not held as soap, as did the constipated stools with the highest soap content. The calcium which could be lost as soap was never a very large proportion of the intake. Even in the stools containing the most soap, it was found to be a very small part of the calcium intake. The calcium lost as phosphate was shown to be increased in soapy stools. The calcium absorption was much lower when diarrhea was present. With an increased excretion of calcium in diarrheal stools, there was a marked decrease in soap excretion.

Hutchinson (42) believed that rickets is due to fat starva-

tion and that the excessive loss of calcium in this condition is not brought about thru the agency of fat. This conclusion is supported by the fact that the average daily excretion of soaps in rickets is 2.2 grams as compared with 2.9 grams in health. Fat could only remove the calcium as an insoluble soap, and as there is no increase of soap in the stools of rachitic infants, there is evidently no connection between calcium loss in rickets and fat excretion.

According to the observations of Wolf (43) the utilication of fat was in no case especially good, but it seemed to have little influence on the metabolism of calcium even when the amount of fat in the diet was greatly increased.

According to Holt, Courtney and Fales (41) the best calcium oxide absorption occurred when the intake of fat exceeded 3.0 grams per kilogram and at the same time for every gram of fat there was in the diet from 0.03 to 0.05 grams of CaO.

The work of Cronheim and Mueller (44) shows that in case of children on an ordinary milk diet, the fecal calcium is not solely combined as soap. Some of it is excreted in this form, but there is a great excess in other compounds. In other words, on a moderately rich fat diet, only a small amount of the calcium is removed by the fatty acids.

A review of the literature on the affect of fat in the diet on calcium assimilation does not justify a conclusion. Some of the investigators maintain that fat feeding is the cause of rickets due to the withdrawal of calcium to form insoluble calcium soaps, while others assure us that fat feeding does not affect the calcium assimilation.

The relation of calcium and phosphorus to rickets. One result of rickets appears to be a low calcium content of the soft

body tissue, while the bones are deficient in both calcium and phosphorus. The work of Carter, Howe, Mason (128) and Ashenheim and Koumheimer (45) indicates that one result of rickets is a low calcium content of the body and muscle. Rost (46) and Gossage (25) found a deficiency of both calcium and phosphorus in the skeleton as a result of rickets. These results suggest that rickets may be due either to a lack of calcium in the diet or to improper calcium absorption. Ramecci Arnaldo (47) observed that infants suffering from rickets were nourished by milk low in calcium content. Dibbelt (48) states that rickets is due to low calcium metabolism, and that children having rickets do not utilize the higher amount of calcium from cows milk and prepared foods. He recommended as the best remedies, a lessening of artificial food and an increase in the calcium content of the diet. According to Schabod (49) calcium retention in rickets is increased by feeding of phosphorus. The phosphorus acts especially upon rachitic bones and brings their calcium content nearer normal.

However, on the other hand rickets may occur with diets rich in calcium as indicated by Bryce (50) who states that rickets is known to occur on foods rich in calcium. Gossage (25) found that rickets is usually due to a deficient or low calcium diet, but it also occurs where the food contains plenty of calcium as with cows milk.

Rickets may also occur on diets deficient or low in phosphorus, but with sufficient calcium. Sherman and Pappenheimer (51) found that rats develop rickets on a sample diet composed of:

| | |
|---|---|
| Patent flour | 95% |
| Calcium lactate | 3% |
| Sodium Chloride | 2% |

or on a ration of :

| | |
|---|---|
| Patent flour | 95% |
| Calcium lactate | 2.9% |
| Sodium chloride | 2% |
| Ferric citrate | .1 |

Rickets on these diets could be cured or prevented by the addition of potassium phosphate in place of the calcium lactate. The work of Pappenheimer, McCann and Zucker (52) indicates that rickets is due to a lack of phosphorus in the diet, but that casein phosphate does not completely prevent the development of rickets.

Some investigators were able to develop rickets on diets low in calcium with a normal phosphorus, while others obtained the same results with diets low in phosphorus, with normal calcium. The recent work of McCollum and his co-workers (52) has aided materially in explaining why rickets is produced on different diets. They were able to develop rickets on diets low in calcium, with phosphorus normal or high; or on diets low in phosphorus, with the calcium normal or high. These workers suggested that there are two kinds of rickets; low calcium rickets and low phosphorus rickets.

## Forms in which the Calcium and Phosphorus can be Utilized by the Animal Body

The forms in which the calcium and phosphorus can be utilized by the animal body is highly important, since these elements play so great a part in the etiology of rickets.

Mashahiko Tanaka (54) injected various calcium salts in doses up to six grams into the body cavities or veins of rabbits. Death resulted after a few days to a week. Calcifications were found in various organs of the body, both near and remote from the places of injections. The chemical nature of the calcium salts injected, some of which were insoluble, some of which were soluble, had no

influence on the nature of the calcifications.

Aron and Frese (55) conducted experiments on two growing dogs to determine the ability of animals to utilize the calcium in the form of tertiary phosphate in raw and sterilized milk. The calcium administration was given in amounts just sufficient to cover the needs of the growing animal. The results show that the calcium requirements may be covered by inorganic calcium in the form of tertiary phosphate as well as milk calcium. Sterilization of the milk had no influence on the utilization of calcium. The absorption of calcium salts either inorganic or organic can occur to the extent of 80 per cent of the ingested amounts.

Emmerick and Loew (56) found that the feeding of $CaCl_2$ to calves and pigs resulted in a 10 to 25 per cent increase in weight as compared with animals on feeds lacking in this element.

Heltcher (57) fed rats on milk and various salts including $CaCO_3$, $CaCl_2$, $Ca_3PO_4$, $Ca_2H_2(PO_4)_2$ and calcium citrate. The rats getting milk plus $CaCO_3$ made the greatest growth by far, while $Ca_3PO_4$ was second, $Ca_2H_2(PO_4)_2$ third, calcium citrate fourth, and $CaCl_2$ last.

Zuchmayer (58) concluded that colloidal potassium phosphates probably play a part in the absorption of calcium supplied in the food.

Weiser (59) found that swine fed on a ration consisting exclusively of corn, showed a loss of calcium and phosphorus, but a slight gain in magnesium. There was a slight gain in calcium and phosphorus on barley and starch. When $CaCO_3$ was fed there was a normal retention of calcium and phosphorus, but a loss of magnesium.

Meigs and his co-workers (19) reported that the assimilation of phosphorus by pregnant cows, and probably that of calcium is

favored by the addition of di-sodium phosphate to the grain, when the grain and hay are fed on alternate days.

Observations were made by Hamilton (60) on four infants born four to ten weeks before full term, receiving human milk from the bottle. Three of these infants had a very low calcium retention during the first month of life. The addition of $CaCl_2$ increased calcium retention.

Schenke (61) concluded that precipitated calcium phosphate was the most satisfactory form in which to incorporate in to the rations for farm animals.

Volhard (62) fed sheep fifty grams of $CaCO_3$ daily in addition to a basal ration of hay and cottonseed meal with a little salt. He concluded that $CaCO_3$ did not materially affect the digestibility of the ration.

Wagner (63) states that the importance of lime for the formation of bone and for the digestion and assimilation of foods is generally recognized, and that under ordinary conditions the rations fed supply a sufficiency of calcium. If, for any reason, this is not the case, and mineral salts must be resorted to, precipitated calcium phosphate of known purity should be used.

Grandeau (64) found calcium phosphate an important addition to the ration of farm animals, where ever the amount naturally supplied by feeding stuffs was insufficient.

Patterson (65) fed rabbits on a diet consisting of oat meal and corn meal, which led to calcium starvation. The ratio of calcium to the total ash in the blood remained about the same as in normal animals. However, the ratio of calcium to total minerals in the bone was not constant, and when the animal was placed on a diet poor in calcium, there was an actual loss of it in the system.

The work of Kohler (66) with lambs indicates that calcium and phosphoric acid are most thoroughly assimilated in the form of precipitated calcium phosphate, which is a mixture of tri-calcium and di-calcium phosphate. Bone meal with the gelatin removed was less thoroughly assimilated.

The results of Bowditch and Bosworth (67) indicate that infants over four months of age can utilize a small amount of the di-calcium phosphate found in cows milk, while younger infants cannot utilize any of it. The addition of lime water to milk results in a precipitation of insoluble calcium phosphate. The calcium of calcium caseinate may unite with the phosphoric acid formed by the hydrolysis of the casein molecule, the insoluble casein molecule thus formed being excreted in the feces. It is possible by excess calcium feeding to precipitate all the phosphorus of the food in the intestine as insoluble calcium phosphate thus reducing the phosphorus metabolism to a very low level.

A review of the literature on the forms in which calcium and phosphorus can be utilized by the animal body, indicates that calcium carbonate and calcium chloride are the best forms to add to a ration deficient in calcium, while di-sodium phosphate is the best form of phosphorus to add to a ration deficient in this element; and where both calcium and phosphorus are deficient, precipitated calcium phosphate is the best form to add to the diet.

## The Vitamine Etiology of Rickets

The theory that rickets is due to the lack of an antirachitic factor in the diet was first suggested by Funk (1914) and first tested experimentally by Mellanby (68) who produced rickets in puppies on a standard diet consisting of milk (175 to 350 cc) wheat bran ad libitum, linseed oil (5 to 10 cc) yeast (5-10 gms.) orange or

lemon juice (3 cc.) and NaCl (2 gms.). The addition of 10 grams of meat a day to the basal diet delayed, but did not prevent rickets, the extent of the delay depending on the initial weight and rate of growth. An increase in the separated milk up to 350 to 400 cc. did not prevent rickets, thus excluding the possibility that the calcium intake was deficient. The addition of 10 grams of butter, or cod liver oil completely prevented rickets, but the substitution of 10 grams of cottonseed oil, olive oil, or linseed oil to the basal ration did not prevent the disease. Mellanby concluded from his results that rickets is a disease primarily due to a deficiency of fat soluble "A" and that substances containing, and associating with fat soluble "A" appear to be particularily concerned in the calcification process of bones and teeth.

In a later work Mellanby (69) states that the requirements of vitamine "A" depends largely upon the composition of the diet. The high protein stimulates the total metabolism, causing greater activity and therefore less of this vitamine is required. On a carbohydrate diet, the metabolism is sluggish and the organism requires more vitamine "A". The fact that large and rapidly growing puppies require more of the antirachitic factor is thought not to be out of keeping with the supposition that fat soluble "A" and the antirachitic factor are identical if it is considered that the function of fat soluble "A" in the diet is not so much to insure growth, as to promote correct growth, in which case the greater the amount of growth in any one period, the greater will be the amount of fat soluble "A" necessary to keep it along normal lines. The antirachitic factor and fat soluble "A" are identical, or at least the distribution of the two substances are remarkably similar. Milk was emphasized as an antirachitic factor and the possibility was suggested that cows fed

in stall largely on vegetable oil cake will give a milk deficient in the accessory food factors, and that if the nursing mothers diet is deficient in the antirachitic factor, the breast fed child may develop rickets.

Mellanby (70) also maintains that age plays a big part in the cause of rickets as it is produced in older dogs with great difficulty.

Tozer (71) found that a kitten on a diet deficient in fat soluble "A" showed marked abnormalities at the costachondral junctions of the ribs. These abnormalities did not resemble those of rickets, but were similar to those noted in guinea pigs deprived of vitamine "A" and also indistinguishable from those caused by a definate but not a severe scurvy.

Funk (72) regards rickets as a disease due to the lack of fat soluble "A"; since if it was not a question of fat soluble "A" it would mean that normal milk contains no substance protective against rickets and therefore most milk fed children would suffer from this disease.

The results of Noel Paton and Watson (73) did not agree with those of Mellanby. They concluded that rickets in dogs is not dependent upon a lack of antirachitic vitamine, but upon the energy content of the diet, exercise and hygiene.

Holt, Courtney and Fales (74) kept a child five weeks on a diet containing vegetable fats, which are practically free of fat soluble "A". The child stopped growing, but remained in good general condition, which indicates that the antirachitic factor may be separate from fat soluble "A".

McCollum and his co-workers (75) fed rats two rations which were low in fat soluble "A" and phosphorus. These diets produced in

a majority of rats placed upon them, pathological conditions of the skeleton having a fundamental resemblance to rickets. The pathological conditions produced are not identical, however, with that disease as it is usually manifests itself in the human being. The chief difference consisted in the presence of scattered or irregular deposits of calcium salts in the cartilege and metaphysis. The picture bore a marked resemblance to those seen in rachitic children in whose bones incomplete healing has taken place. When the deficiency in phosphorus is compensated for by the addition of a complete salt mixture containing the phosphorus ion, the deficiency in fat soluble "A" still existing, no pathological changes of a rachitic nature developed. Therefore, a deficiency of fat soluble "A" in the diet can not be the sole cause of rachitic like changes in the skeleton, since the addition of phosphorus to the diet prevented this condition, but has no effect in preventing ophthalmia. It seems permissable to infer from these results that ophthalmia and rickets do not have an identical etiology.

Although fat soluble "A" and the antirachitic factor are closely associated, the recent investigational work indicates that the two factors are not identical. McCollum has just recently suggested the name of vitamine "D" for the antirachitic factor.

Cod liver oil as a source of the antirachitic factor. It has been known for a considerable length of time that cod liver oil aids in curing rickets, and is regarded as the "specific" for this disease. The reason why cod liver oil aids in the cure of rickets has long been a mystery, but the most recent investigations indicate that it contains the antirachatic vitamine which aids calcium and phosphorus retention, thus preventing rickets.

The presence of an antirachitic factor in cod liver oil is

indicated by the work of Towles (76), Birch (77), Gismondi (78), Hall (37), Gossage (25) and Holt, Courtney and Fales (4) who were able to increase the calcium retention by the addition of cod liver oil to the diet. Schabod (37) increased the retention of both calcium and phosphorus by the use of cod liver oil. Park and Howland studied 50 cases of rickets in which cod liver oil was administered. They concluded that cod liver oil brings about a change in the bones amounting to a complete cure if the diet was not faulty.

Further proof that cod liver oil contains the anti-rachitic factor is presented by Hart, Steenbock and Hoppert (79) who changed a negative calcium balance into a positive balance in a lactating goat by the administration of cod liver oil; and the work of McCollum and his co-workers (80) who found that rats on a low calcium diet were much better nourished when supplied with 1 per cent cod liver, than with 10 per cent to 20 per cent butter fat as shown by better growth, fertility, success in rearing young and length of life. They concluded that cod liver oil contains some substance in abundance which is present in butter fat in but very small quantities, and which exerts a directive influence on the bone development even when the calcium supply is inadequate.

Green plants as a source of the antirachitic factor. Certain green materials seem to contain an antirachitic factor, similar to that found in cod liver oil.

Rose (81) fed carrots to healthy women which caused a greater calcium retention.

Carter, Howe and Mason (82) stated that good cows' milk was lacking in some particular, which they suggested may be an anti-rachitic factor, since they were unable to cure rickets with milk, but obtained good results by feeding fruit juice, beef juice, eggs,

potatoes and green vegetables.

Hess and Unger (83) pointed out that negroes in a certain district in New York came from the West Indies, where their diet consisted mainly of vegetables and fruit; and that the sudden change to a diet in which meat was one of the principal ingredients, to the virtual exclusion of fruits and vegetables, may have so altered the metabolism of the mother and her offspring as to be one of the etiological factors in the production of rickets.

Robb (84) states that guinea pigs on a diet of dried plants for fourteen to twenty one days eliminated twice as much calcium as those receiving a green diet.

Hart, Steenbock and Hoppert (79) obtained a negative calcium balance when cabbage was fed to goats, and orange juice also failed to alter calcium metabolism which led them to conclude that the anti-scorbutic factor was not instrumental in producing calcium assimilation. However, when fresh green oats were compared with dry oat straw, the green oat straw increased the amount of calcium assimilated. Like results were obtained with oat hay dried out of direct sunlight, but in a fairly well lighted attic. Their data show that the same factor affecting calcium assimilation and resident in green oats and grasses, is present in cod liver oil.

Freise and Ripprecht (85) found that calcium was assimilated better under the influence of vegetables, but they also found that influence was lacking when the vegetables or juices had been heated considerably before feeding. They therefore concluded that it was not a fat soluble factor, but a water soluble vitamine that is deficient in rickets.

It is evident that some green plants contain the antirachitic factor, but it is not a constituent of all green plant tissue.

## Tetany (Spasmophilia)

Tetany usually occurs with rickets, but not necessarily so. Both rickets and tetany are diseases of childhood, due to dietary causes, and both are relieved by feeding calcium. However, they are not identical, since in rickets the bones suffer due to a lack of calcium, while in tetany the muscles and nerves suffer due to a deficiency of this element.

The relation of rickets to tetany has recently been pointed out by McCollum and his co-workers (53) who state that tetany is associated with low calcium rickets.

Calves fed on milk exclusively developed symptoms similar if not identical to those of tetany, which suggest the idea that calves on such a diet develop tetany. This idea is strengthened by the results of Eckles and Wilbur who were able to prevent and cure this condition by feeding calcium.

Spasmophilia and tetany mean the same thing, but the former is usually applied to the spasms or tetany of human infants. The American Medical Dictionary (10) defines tetany as a disease characterized by painful tonic and symmetric spasm of the muscles of the extremities, which occurs after typhoid fever, diarrhea, exposure to cold, rickets and the removal of the parathyroid glands.

According to Elterich (86) Professor of Pediatrics, University of Pittsburg, the term tetany means a spasmophilic condition characterized by prolonged contractions of the muscles of the extremities and extreme irritability of the nervous system to mechanical and electrical stimulation. The underlying cause of tetany occurring in young children may be safely attributed to rickets, and in older children to a neurotic condition.

According to McCollum and Voegtlin (87) the symptoms of tetany in a general character are the same in all forms. They depend on increased excitibility of the central nervous system, which may be recognized by quantitative tests with farodic and galvanic currents; also by the spasmodic rigidity of the muscles, frequently with violent twitchings, which may become so intense and general as to constitute an epiliform convulsion. Fibrillary tremors of the tongue and distorting contractions of the facial muscles are often met with, and the jaws may be so tightly clinched that speech or the taking of food is impossible.

McClean (88) states that tetany is the most common in winter and that there is very little of it in the summer. Tetany is a rare disease in the Southern States and California. On the other hand, however, there is but little tetany in Sweden and Russia, where there is little sunlight five months out of the year. Out of 47 cases studied by McClean, only three were under three months of age, while the average was ten months, which indicates that tetany is not a disease of the very young infants.

The results of Stoelzer (89) indicate that latent tetany can be influenced by the diet, and that the administration of cows' milk causes aggravation of the galvanic hyperexcitability. These disappear on the withdrawal of milk and free purgation.

Kassowitz (90) maintained that tetany is just a symptom of rickets, while Howland and Marriot (91) found tetany occasionally in infants who presented no sign of rickets.

According to an editorial in the Journal of the American Medical Association (92) tetany is essentially an expression on the part of the nervous system of an insufficiency of the calcium ion, where as rickets is the expression on the part of the skeleton of dis-

turbed relations between the calcium and phosphorus ions of the body fluids. It is readily conceivable from this explanation how the two disorders may be simultaneously manifested.

McCollum and his co-workers (53) consider tetany as an expression on the part of the nervous tissue of an insufficiency of the calcium ion; and rickets as an expression on the part of the skeleton of disturbed relation between the calcium and phosphate ions in the body fluids. Tetany is frequently associated with rickets, especially that form of rickets in which the calcium ion in the body tissues and fluids is subject to variations. Tetany occurs independently of rickets, just as rickets occurs independently of tetany. Since tetany may occur with low phosphorus form of rickets, it does not serve to mark off one form of rickets from another. Tetany, however, is essentially associated with the low calcium form of rickets, and for all practical purposes the low calcium rickets is the rickets of tetany.

Low calcium in the tissues as the cause of tetany. According to the most widely accepted theory, tetany is due to low calcium in the tissues. Quest (93) was the first to find that the calcium content of the brains of patients dying in tetany was distinctly diminished when compared to the normal brain of the same age. Sabbatoni (94) was the first to suggest that a decreased content of calcium in the brain caused the irritability of the nervous tissue, since he had observed that when $CaCl_2$ was applied to the cortical surface, the irritability was immediately reduced. With antagonistic agents such as sodium citrate, the reverse is true. He thought that this might be a factor contributing to the cause of convulsive disorders.

According to Hans Meyers (95) calcium salts have a sedative effect on the sympathetic nervous system, and diminish the permeability of the walls of the blood vessels. When they are withdrawn from

the system, the result is over-excitability of the whole viscera and cerebro-spinal motor nervous system.

The experiments of Schwarz and Bass (96) indicate that calcium retention is lowered in tetany.

Cottonea (97) observed a decrease in calcium content of the body in six cases of spasmophilia.

Klein (98) found that as calcium was given and retained, the tetany subsided. The retention of calcium increased under parathyroid and thyroid treatment. The greatest retention followed daily doses of three grams of calcium lactate.

The results of Underhill and Blatherwick (99) show that the lack of sugar in the blood was not the cause of tetany. However, in cases of tetany with low blood sugar, the injection of calcium lactate temporarily restored the blood sugar, and also abolished tetany. They suggested that apparently the calcium was closely associated both with the sugar regulating mechanism and with the effect on the nervous system which produces the tetany, and that calcium may play an important part in maintaining the equilibrium of the mechanism regulating the blood sugar during normal life.

MacCallum, Lambert and Vogel (100) removed the calcium from blood by dialysis, which, when perfused through an isolated extremity produced an extreme hyperexcitability of the nerve quite like that in tetany, hyperexcitability being due to a lack of calcium. Normal blood immediately relieved tetany.

Opitz (101) reported that in communities using drinking water high in lime, that there was less dental trouble in the school children and registrants for military service. Also there was greater vitality in the newly born and less frequent signs of nervous hyperexcitability in infants.

Scherer (102) states that while the chemistry of the blood may not reveal changes in the calcium content, there is a hyperexcitability of the nervous system which can be shown by the electrical reactions. The condition is relieved by the use of liberal doses of calcium combined with cod liver oil.

Kramer, Tisdall and Howland (103) found the calcium content of the serum much diminished and the irritability of the nerves greatly increased in tetany. They found that $CaCl_2$ by mouth, frequently repeated, will abolish evidences of active tetany and will increase the calcium concentration of the blood serum to nearly normal. Ten to fifteen grams of $CaCl_2$ were used every four hours.

MacCallum and Voegtlin (87) were able to stop the symptoms of tetany by giving 100 cc. of 4.3 per cent of calcium lactate by the stomach pump. However, their results show that calcium administration in tetany is very similar, no matter whether given intravenously, subcutaneously, or by the stomach tube. The rapidity with which the calcium acts differs, under these different conditions. $CaCl_2$ is perhaps the most irritable of the calcium salts, and can not well be administered subcutaneously. Too rapid injection of calcium lactate into the venous system may give rise to hemorrhages in the pulmonary tissue. No other ill effects were observed when large doses of calcium were administered rapidly.

According to Marine (104) calcium salts have a preventative action in tiding over otherwise fatal cases, but are in no sense curative.

On the other hand, Ott and Scott (105) maintain that tetany is not due to a lack of calcium, but to a poison in the blood. Naville (106) also states that even latent tetany, indicated by electrical test did not confirm their assumption that the lack of calcium

is a factor in the tetany of man.

Pereda (107) maintains that rickets and spasmophilia are not due principally to the deficiency in calcium, as infants fed on an insufficient amount of breast milk do not show these symptoms. Cows' milk, although containing more calcium, breeds rickets.

Von Meysenburg (108) concluded that there is no change in the proportion of diffusible serum calcium in human rickets or experimental tetany.

Stoelzer (90) does not regard a deficiency of calcium as the cause of tetany. His experiments show that calcium added to the muscles of children with tetany increase the galvanic irritability. He also states that nearly all children with tetany are troubled with intestinal disorders, and that cows' milk which is high in calcium, is harmful to such children, while human milk, which is low in calcium content is helpful. The results of Stoelzer are not in harmony with those of other investigators.

It is evident from the review of literature that low calcium in the tissues occurs in tetany and that the tetany is relieved by bringing the blood calcium up to normal, either by feeding or by injecting calcium solutions.

The role of parathyroids in tetany. The parathyroid glands are small, pale, glandular masses, either imbedded in the thyroids, or lying close to them, or attached to the thymus gland, usually four in number in herbivera. Complete extirpation is generally followed by the symptoms of tetany which can be relieved by giving calcium lactate. They seem to play an important part in the retention of calcium.

Metabolism in parathyroidectomized animals was studied by MacCallum and Voegtlin (87) who found a marked reduction in the calcium

content of the tissues, especially of the blood and brain during tetany, and also an increased output of calcium in the urine and feces. They suggested that parathyroid secretion in some way controls the calcium exchange in the body. It may possibly be that in the absence of the parathyroid secretion, substances arise which combine with the calcium, thus removing it from the tissues and causing its excretion. The parathyroid secretion prevents the appearance of such bodies. The mechanism of the parathyroid action is not known, but the result, the impoverishment of the tissues with respect to calcium and the consequent development of hyperexcitability of the nerve cells, resulting in tetany is proven. Only restoration of calcium to the tissues can prevent this. The injection of calcium salts into the circulation, promptly checks symptoms of tetany when present.

Arntzenias (109) found that patients suffering from post-operative tetany could be relieved of the symptoms by the administration of 4 grams of $CaCl_2$ or calcium lactate daily, but there was no improvement when cows and sheep parathyroids, fresh and desiccated, were fed. He concluded that hypo-functioning of the parathyroids changes the calcium metabolism, and thereby gives rise to tetany.

Farmer and Kluger (110) removed the thyroids and parathyroids in 40 cats of various ages. Tetany, acute or chronic, followed in a large number of cases; in some cases acute attacks could be modified by a suitable calcium diet. The therapeutic use of lime never failed in staying acute cases of undoubted tetany, but the effects lasted but one or two days, hence the treatment must be continuous. These experiments led to the conclusion that the function of the parathyroid glands, owing to chemical affinity between the protoplasm of their cells and toxic bases (guanidin and methyl-guanidin, which normally occur in the blood and are eliminated through the urine) is to

attract the latter from the blood and neutralize their effects. Calcium chloride in the laboratory experiments was found to produce an insoluble precipitate with guanidin carbonate, which is an explanation of the therapeutic effect of calcium salts in tetany.

According to Poppens (111) tetany following thyroidectomy is rather uncommon. Although tetany is a manifestation of an increased irritability of the nervous system, it represents only a snydrome which may be well controlled by calcium salts, and it is not necessarily the entire expression of the abnormality following parathyroidectomy. Calcium and the other nerve depressents such as strontium will prolong the life of animals with removed parathyroid glands for a few days but will not save them.

On the other hand, however, Luckhardt and Rosenbloom (112) were able to keep dogs alive, where the parathyroids had been removed by the injection of calcium free solution, known as Ringers solution. They concluded that an active diuresis produced with the elimination of toxic compounds is more important than the administration of calcium compounds.

It is apparent from this discussion, that the parathyroids play a role in calcium retention. There is a possibility that milk is deficient in some factor necessary for the proper functioning of these glands.

Alkalosis as the cause of tetany. Alkalosis often occurs with tetany, which suggested the idea that the convulsions of calves fed on whole milk alone might be due to an excessively large amount of basic material in the blood.

Alkalosis was defined by Wilson, Stearns and Thurlow (113) as a pathological condition in which the basic radicles in the blood are relatively increased over the acid radicles, disregarding carbonic

acid. This definition does not specify whether the bases are absolutely increased or the acids, not $CO_2$ are decreased, or whether both phenomena occur. Nor does it imply that the blood in the body is more alkaline than usual, for an increased tension of $CO_2$ may neutralize any tendency toward a decreased hydrogen ion concentration and maintain a final reaction differing little from the normal. They found no changes in the pH of the blood in tetany.

Wilson, Stearns and Janney (114) made intravenous injections of HCl in NaCl which relieved parathyroid tetany in dogs, the time elapsing before the return of the symptoms varied with the amount of acid, but in some cases it extended over several days. The NaCl alone had no apparent beneficial effect. The same effect was produced when the HCl was taken by mouth, but this method of proceeding is usually not efficient, owing to the difficulty with which material is retained in the stomach of dogs in tetany. The results suggest that there may be a condition or tendency toward an alkalosis after parathyroidectomy which is relieved by the introduction of acids.

Wilson, Stearns and Janney (114) also found that injections of suitable quantities of ammonium salts produce tetany. They obtained relief from tetany by the introduction of strontium, magnesium, and barium, as well as calcium salts. Sodium bicarbonate, sodium acetate, and potassium acetate have been shown to be distinctly harmful in tetany. The conclusion is that alkalosis is harmful in tetany, while acidosis is beneficial.

Binger (115) and Harrop (116) were able to produce tetany in dogs by the injection intravenously, of neutral or alkaline solutions of sodium orthophosphates. There was a diminution in the calcium content of the serum, which depended upon the amount of phosphate introduced. Although acid phosphates produced a drop in the serum calcium,

no tetany was produced, consequently the part played by the calcium in the production of tetany was not clear.

Jeppson and Klercher (117) relate that invariable development of tetany with carpopedal spasm in a child seven years old, when fed sodium phosphate by the mouth, while it did not show these symptoms at other times, which confirms the view that the spasmogenic substance in the milk is the whey, and that only the salts in the whey, and probably only the alkaline phosphates, are responsible for the symptoms called spasmophilia. His research work demonstrated that latent spasmophilia was not affected by whey which had been deprived of its phosphates. Also that children displaying a tendency to spasmophilia had been getting excess of alkaline phosphates. The property of the alkaline phosphates to reduce the calcium content of the tissue, is a further element in their injurious action.

Collip and Backus (118) also maintained that tetany is due to alkalosis (too much alkali in the blood and tissue) even going so far as to suggest that muscle "cramp" is due to alkalosis.

Hastings, Murray, C.D. and Murray H.J. (119) suggested that alkalosis is an exaggeration in duration and extent of the alkaline tide occurring abnormally after meals. The secretion of HCl by the cells of the gastric mucosa necessitate the removal from the blood stream H ions and Cl ions.

On the other hand, Henderson (120) was unable to produce the symptoms of tetany by the administration of alkali.

The consensus of opinion among the investigators is that alkalosis may produce the symptoms of tetany. The idea that alkalosis is an exaggeration in duration of the alkaline tide occurring abnormally after meals, may explain why calves on an exclusive milk diet, often go into convulsions immediately after feeding.

Ion antagonism as the cause of tetany (spasmophilia). A theory that tetany or spasmophilia is due to an irritant effect of certain ions on the body tissue, has been advanced by several investigators. Loeb (121) experimenting with frogs, found that when certain ions came in contact with the nerves a tetanus condition resulted, while other ions if present tend to counteract the irritating effect. He was able to produce contact irritability with sodium fluride, disodium phosphite, disodium phosphate, sodium oxalate, sodium citrate, sodium tartrate and acid sodium carbonate, or the sodium compounds whose anions form insoluble calcium compounds. The tetanus of the muscle in the presence of certain sodium salts, may be due to the OH ions in the solution as OH and H ions have a catalytic action and speed up the contraction due to the Na ions. The muscles constantly produce $H_2CO_3$ and possibly other acids, which increase the solubility of the calcium salts and increase the number of the calcium ions in the tissues. An addition of OH ions will counteract this effect. Alkalinity seems to aid sodium ions in producing irritability. The addition of $CaCl_2$ to a sodium citrate solution stopped the contact reaction.

Also Joseph and Meltzer (122) were able to completely inhibit all irritability of nerves and muscles by a primary perfusion of the muscles of a frog with M/10 $CaCl_2$, this inhibition was promptly reversible by a subsequent irrigation with M/10 NaCl. They found that $CaCl_2$ in its primary action abolished the irritability of nerve trunks, muscle tissue, and the motor nerve endings.

Nassau (123), Lovett (124) and Emmerick and Loew (125) state that tetany is a condition in which the normal balance between calcium and magnesium on one side, and sodium and potassium on the other, is disturbed so that there is a relative diminution in the proportion

of calcium and magnesium, and a consequent increase in the irritability of the nervous system.

Healy (126) reported where 1200 grains of sodium bicarbonate were given to a patient after an operation on the pelvic viscera, instead of 180 grains as planned. This upset the normal relations between sodium and potassium, calcium and other ions in the neuro muscular tissue, resulting in tetany.

According to Tisdall, Kramer and Howland (127) the average concentration of the following elements in the sera of normal children is:

| | | | |
|---|---|---|---|
| Calcium | 10 to | 11 | mg. per 100 cc of serum |
| Magnesium | 2 to | 3 | mg. per 100 cc of serum |
| Sodium | 325 to | 345 | mg. per 100 cc of serum |
| Potassium | 18.5 to | 20.5 | mg. per 100 cc of serum |

while the average concentration of the same element in infantile tetany is:

| | | |
|---|---|---|
| Calcium | 5.8 | mg. per 100 cc of serum |
| Magnesium | 2.1 | mg. per 100 cc of serum |
| Sodium | 327 | mg. per 100 cc of serum |
| Potassium | 24.9 | mg. per 100 cc of serum |

The sodium content falls within the limits of normal, the potassium content is somewhat elevated and the calcium is markedly diminished. The (Na + K) (Ca + Mg) ratio in normal infant blood is:

$\frac{340 + 14.9}{10.5 + 2.5} = \frac{27.6}{}$ while in the case of active infantile tetany it is

$\frac{327 + 24.9}{5.8 + 2.1} = 44.5$

This change is due almost entirely to the lower calcium concentration.

The results of these investigators show that sodium and potassium ions produce irritability while calcium and potassium ions repress this condition, and that tetany is due to the presence of more sodium and potassium than calcium and magnesium ion in the body tissues.

## Discussion of the Review of Literature

The failure of calves to grow from birth to maturity on milk as the sole diet was first pointed out by Davenport twenty five years ago. He found that calves come down with convulsions at about four months of age, from which they soon die, when milk or grain form their sole diet. These results were confirmed by the recent investigations of McCandlish, and by those of Eckles and Wilbur.

Davenport and McCandlish attributed the failure of calves to survive on milk to a lack of roughage. However, the recent work of Hughes and Cave indicates that calves can be grown to maturity without roughage. They were able to raise a calf to one year of age on milk alone. At this age, bone ash was added to the diet and the calf continued to grow without roughage. Also Eckles and Wilbur raised a calf to eight months of age on whole milk and calcium carbonate. At this age it appeared normal in every respect, and was sold as a herd sire.

These results point to the possibility that calves fed exclusively on milk, develop convulsions due to a lack of minerals or to an improper utilization of the minerals in milk, and that in all probability calcium is the limiting element. These results also suggest the possibility that calves on an exclusive whole milk diet may develop acidosis or some form of rickets, which are diseases due to improper mineral metabolism.

The fact that convulsions often occur with acidosis, suggested the idea that the convulsions which whole milk calves develop may be due to faulty absorption of minerals, resulting in acidosis, which is measured by determining the alkaline reserve of the blood. Since the alkaline reserve is lowered materially in this disease,

investigators are fairly well agreed that the alkaline reserve of the blood can be altered by nutrition.

Rickets is a disease of the bones, which some authorities attribute to improper mineral metabolism, especially calcium and phosphorus. Eckles and Wilbur were able to relieve convulsions in whole milk calves by feeding calcium carbonate, which indicates a rachitic condition, due to low calcium retention.

Milk is fairly high in minerals, especially calcium, but calves fed on it exclusively may not be able to utilize the calcium efficiently, due either to the calcium uniting with the fat of the milk, forming insoluble calcium soaps which are lost in the feces; or to a lack of the antirachitic factor which aids in calcium absorption.

Investigators are not agreed as to the effect of fat feeding on calcium assimilation. Some maintain that fat in the diet causes the loss of calcium in the feces in the form of insoluble calcium soap, while others assure us that fat feeding does not produce a calcium loss. This question is far from being settled.

Another causative factor in rickets is the lack of phosphorus in the diet, or to its improper absorption, as shown by the work of some investigators, while the results of others uphold the theory that rickets is due to a calcium deficiency. The recent work of McCollum and his co-workers shows that both ideas are correct, since they were able to develop rickets experimentally with low calcium with normal phosphorus diets, and also with low phosphorus with normal calcium diets. In other words, there are two kinds of rickets.

Calves may not be able to utilize the calcium in milk due to a lack of the antirachitic factor, which aids in calcium retention. The existance of an antirachitic factor was first suggested by Funk in 1914, but was considered identical with fat soluble "A" until

recently. The most recent investigators show that this factor is usually associated with fat soluble "A", but that it is not identical with it. McCollum has just recently named the antirachitic factor, vitamine "D". This vitamine is found in the greatest amount in cod liver oil and certain green plants.

Sunlight has the same effect on calcium retention and on rickets as the antirachitic vitamine. Rickets have been cured with the direct rays of the sun. Hughes and Cave raised two calves to one year of age on milk alone, due possibly to the influence of exercise and sunlight.

McCollum and his co-workers pointed out that low calcium rickets is the rickets of tetany, which suggests the idea that calves fed whole milk may develop tetany, since the symptoms are similar if not identical. A review of the literature shows that tetany can be cured either by feeding calcium or by injecting calcium ions into the tissue, which is another indication that the convulsions of whole milk calves are simply the symptoms of tetany, since feeding calcium carbonate relieved the situation.

According to another theory, tetany may be due to alkalosis. This is a condition, where the alkaline reserve of the blood is abnormally high. Acid injection relieved this kind of tetany.

The idea that tetany is due to an increased proportion of irritating or stimulating ions in the tissue, over the ions that tend to suppress irritability, is suggested by the work of several investigators. According to this theory, the sodium and potassium ions produce irritability, while calcium and magnesium repress or counteract this irritability. Tetany is a result of a greater number of sodium and potassium ions than calcium and magnesium ions in the tissue. In other words, tetany is an exaggerated irritability due to a lack

of calcium and magnesium in the tissue. If calves on a whole milk diet fail to absorb a sufficient amount of calcium and magnesium in proportion to the sodium and potassium retained, tetany results.

# EXPERIMENTAL WORK

## OBJECT OF EXPERIMENT

It has been known since the time of Davenport, twenty five years ago, and recently confirmed by McCandlish, that calves on an exclusive milk diet come down with convulsions before the age of six months, from which they soon die.

In the light of the present knowledge of vitamines, Dr. Eckles suggested the possibility, that milk may be deficient in vitamines which are necessary for the proper nutrition of calves. With this idea in mind, Eckles and Wilbur placed four Holstein calves on an exclusive diet of whole milk, with the object in view of determining the vitamine deficiency.

All four calves came down with convulsions at about four months of age. The convulsions were usually preceded by an excitable or nervous condition and a chewing of the tongue, especially while drinking. The convulsions in whole milk calves are characterized by choking, rolling of the eyes, a staggering gait and trembing of the body. The animal then falls on one side, muscles become very tense and rigged, and head thrown back; breathing is rapid and difficult, and at times stops completely for a few seconds, froths at the mouth and in severe attacks may bellow and kick violently. Convulsions eventually cause death, but the first few are not ordinarily fatal.

The possibility that milk is deficient in water soluble "B" vitamine was eliminated by the failure of yeast, which is a rich source of this vitamine to relieve convulsions when added to the diet.

Orange juice, which is a rich source of water soluble "C" when added to the diet of calves with convulsions, failed to relieve the condition. This shows that milk as the sole diet for calves is not deficient in water soluble "C". Evidently the deficiency is not one of vitamine "A", "B", or "C".

Convulsions were relieved in one calf by feeding timothy hay, which appears to justify the conclusion of Davenport and McCandlish, that calves require roughage after they reach a certain age. However, sawdust and filter paper fed with the milk to furnish roughage, did not relieve the convulsions.

The symptoms exhibited by whole milk calves are similar to those of mineral starvation as described by Forbes# and also similar to those of acidosis, which is a disease attributed by some investigators to a loss of alkali minerals, especially calcium, in the feces as insoluble soap. This suggested to Dr. Eckles the possibility of a mineral deficiency in milk as the sole diet for calves, due to possibly either insufficient calcium in the diet, or to a loss of calcium in the feces due to the fat in the milk.

With these ideas in mind, a calf was placed on a ration of whole milk and calcium carbonate, and another was fed skim milk and starch.

The object of this experiment was to continue the work of Eckles and Wilbur, and to further study the cause of the deficiency of milk as a sole diet for calves.

On account of the limited amount of data available, it appears advisable first of all to repeat the experiments made by

# Ohio Station Bulletin 201. P.140.

Eckles and Wilbur, with some modifications in order to make certain the possible relation of water soluble "B" and the antiscorbutic vitamine to the condition in milk fed calves. The work already done points towards an important relation to calcium, and this point was to receive special attention, with an attempt to determine if the calf under these conditions is suffering from acidosis or low calcium rickets which is manifested by the symptoms of tetany.

## PLAN OF EXPERIMENT

The plan of this experiment consists of:

(1) Determine alkaline reserve of the blood of calves on various diets from time to time as a test for acidosis or alkalosis.

(2) Feed whole milk alone until calves come down with convulsions and then test the effect of adding the following to the ration: (a) calcium carbonate, (b) calcium carbonate plus cod liver oil, (c) yeast, (d) orange juice.

(3) Feed whole milk plus calcium carbonate from the beginning to determine if the deficiency of milk is due to a lack of calcium.

(4) Feed a calf skim milk plus starch to increase the energy for the purpose of determining if the fat in the whole milk is a factor in calcium assimulation.

(5) Feed whole milk plus cod liver oil to determine the effect of cod liver oil on calcium retention.

(6) Feed whole milk alone until calves come down with convulsions and then relieve by the injection of calcium chloride or calcium lactate solutions (subcutaneously or intravenously).

(7) Feed milk alone to a five months old calf which has been receiving grain and roughage, to determine the effect of an exclusive milk diet on older calves.

Choice of animals

Three grade Holstein and two pure bred Holstein calves were used in this experiment.

Choice of rations

The rations consisted of (1) sweet whole milk from cows in the Holstein herd, (2) skim milk separated from mixed herd milk, (3) pure corn starch, (4) sucrose sugar, (5) dried bakers yeast, (6) orange juice from fresh oranges, (7) Norwegian cod liver oil and (8) powdered calcium carbonate and tricalcium phosphate.

Care, shelter and feeding methods

The animals were fed and handled by a competent feeder under the supervision of the men conducting the experiment. The calves were kept in individual stalls, sheltered by a small barn, and were allowed to exercise in a small lot free from edible material. Bedding in the form of shavings was provided.

The animals were fed regularily in the early morning and late afternoon. All feeds were weighed on scales graduated to pounds and tenths, except the yeast, calcium carbonate and tricalcium phosphate which were weighed on more delicate scales sensitive to a gram. The orange juice and cod liver oil were measured in a cylinder, graduated to ounces and cubic centimeters. The milk was weighed into clean pails before each feeding. The yeast, starch, sugar, calcium carbonate, tricalcium phosphate and orange juice were stirred into the milk and fed with it. The cod liver oil was fed as a drench. The calves were watered once a day. During the winter the chill of the cold water was eliminated by warming. Free access was given to common salt (Na Cl).

Collection of experimental data

Weighing:

Each animal was weighed three days in succession at the beginning of the experiment and afterwards at intervals of ten days and at thirty day intervals. Weights on three successive days were taken, and the average of the three weighings taken as the initial weight of the animal. The weights were taken in the early morning after feeding, but before they were watered.

Height measurements:

Height measurements at the highest point of the withers were taken at thirty day intervals. The average height of three height measurements, which were within the limits of one centimeter was taken as the height. The animal was moved a short distance between each of the three measurements, which eliminates the error due to the settling down of the animal by relaxation of the muscles.

Record of feed:

The feed fed was recorded on a special feed sheet, when weighed. The feed refused was also recorded.

Record of growth:

The weights and heights were observed at times previously stated, and compared to the average normal of the breed. These were recorded on a special sheet.

Photographs of animals:

Photographs of the calves were taken from time to time. The pictures were taken at an especially prepared place, and the camera was located the same distance from the calf each time.

Observations concerning health of animals:

The animals were observed every day by the feeder and men in charge of the experiment. All symptoms of sickness or disease were recorded promptly.

The alkaline reserve of the blood:

The blood from the calves was taken from the jugular vein into oxalated centrifuge tubes from time to time. It was then centrifuged to separate the serum from the cells. The alkaline reserve of the serum was taken as the average of two determinations by the Van Slyke method.

Autopsy of dead animals:

The staff of the Veterinary Division of the University performed the post-mortem on the calves which died on this experiment.

Experimental Data

A description of calves used in this experiment is found in Table 1. The total feed consumed, the nutrients received and the digestible crude protein and net energy expressed in pounds and therms respectively are contained in Tables 4, 6, 8, 10 and 12. The values used in determining the nutrients in the feeds are shown in Table 2.

Growth figures secured by weighing and measuring the animals as previously indicated are found in Tables 3, 5, 7, 9 and 11. These Tables also include the normal weight, and height at withers of animals of the same age. They further include a direct percentage comparison with the normal.

The Tables are found in the appendix.

Calf V-5. The calf was placed on experiment April 3, 1921 and continued until eight months of age. The ration fed consisted of whole milk and calcium carbonate.

Observations by feeder and men in charge:

This calf gained in thrift and vigor throughout the experiment, and only for one day during the entire period, did it show an indication of sickness, which was due to a slight attack of indigest-

ion.

It was taken off the experiment at the age of eight months, 105.7 per cent normal in weight and 99.3 per cent normal in height and appeared normal in every respect. The animal was sold to C. Hammar as a herd sire. Plate 1, is a photograph which shows him at the close of the experiment.

Calf V-6. The calf was placed on experiment April 3, 1921 and continued until its death February 2, 1922. The original ration fed consisted of skim milk and starch. The starch was added to meet the energy requirement of the animal.

Observations by feeder and men in charge:

The calf first showed a distinct nervousness and a fear of any unusual or moving thing at the age of 163 days. At this point sugar was added to the ration to increase the energy of the food intake. The sugar, however, did not prevent the calf from losing weight. During the seventeenth ten-day period, 60 grams of yeast was fed daily, to determine if the ration was deficient in vitamine "B", but the loss in weight amounting to one pound a day continued during the yeast feeding period.

At the age of 184 days, there were evidences that the calf had undergone a convulsion. Cod liver oil (2 ounces per day) was then added to the ration, assuming in view of recent development that it would increase calcium retention. It was assumed that the convulsions were due to a lack of proper calcium absorption. A convulsion appeared three days following the addition of cod liver oil to the diet, after which the calf apparently began to improve in every way. During the first thirty days of cod liver oil feeding, the calf gained 39 pounds in weight.

At the age of 235 days, and 30 days after starting the

cod liver oil feeding, the calf became sluggish and was able to get up only with great difficulty. The following day it lost the use of the leg muscles entirely and was unable to get up on its feet. Calcium carbonate was added at this time to the diet of skim milk, starch, sugar and cod liver oil. Forty-five grams of calcium carbonate were first fed and gradually increased to sixty grams daily. The animal was exercised by placing in a sling which gave it a chance to use the legs. The front legs were helpless, while the hind ones showed some signs of life.

The calcium carbonate in the diet increased the firmness of the feces, which up to that time had been very liquid. The calcium carbonate resulted in an improved condition after two weeks of feeding. About this time however, the animal threw a fit of very short duration, which may have been a struggle on the calf's part to get up on its feet. The hock joints were very much swollen at this time.

Improvement was evident as the calcium carbonate feeding continued, for at times it was able to get up and stand on three feet for a few seconds. After five weeks of calcium carbonate feeding, during a fit on the part of V-7, V-6 became so excited that it stood up on its hind feet and front pasterns. Three days later it stood alone for a period of one-half minute. The front legs were so crooked that they resembled half circles. It rested the weight on its toes, unable to straighten out the pasterns. However, the swelling had all disappeared from the back joints. About this time, the calcium carbonate was replaced by tricalcium phosphate, which within ten days brought about the same helpless condition which had prevailed previous to feeding calcium carbonate. The addition of one-half calcium carbonate and one-half tricalcium phosphate failed to bring about an improvement.

In an endeavor to get this animal on its feet, practically every available feed was offered, including whole milk, grain mixture, silage and alfalfa hay, but to no avail, eventhough the appetite was good. The calf would eat the feed and then chew its cud and appeared in good spirits, but it never regained its feet. Death occurred at the age of 320 days following an apparently improved condition.

The bones and joints were examined and appeared normal.

Photographs of this animal are found on Plates 2, 3, and 4 in the appendix.

Calf V-7. The calf was placed on experiment September 23, 1921 and continued until death December 12, 1921. Its ration consisted of whole milk alone.

Observations of feeder and men in charge:

The calf made a gain of 27 pounds in the ten day period previous to its first fit, which occurred at 169 days of age, 74 days after being placed on a whole milk diet. It showed no signs of hesitating in drinking and non-control of tongue as exhibited by the other V calves which came down with convulsions, but the other symptoms were similar, except the convulsions in this calf were much more violent and lasted a longer time than with the calves which had previously come down with these symptoms. The convulsions in this calf usually lasted about an hour. At the age of 175 days, and 74 days after being placed on a whole milk diet, it died in a violent convulsion which lasted approximately two hours.

A post-mortem examination revealed a hemorrhagic condition in the nervous tissue and heart, but biological tests failed to show any evidence of hemorragic septicemia. The other organs were normal. An ex-ray examination of the femur, tibia, hock joint and tail failed to show any bone changes that would indicate rickets. These pictures

are found in Plates 8, 9 and 10 in the appendix.

Calf V-8. The calf was placed on experiment September 23, 1921 and continued until death May 23, 1922. The ration fed consisted of whole milk alone.

Observations of feeder and men in charge:

The alkaline reserve of the blood was determined by the Van Slyke method December 23, 1921, 91 days after starting the experiment. The purpose was to determine whether or not whole milk calves develop acidosis, which is measured by a decrease in the alkaline reserve of the blood.

| | |
|---|---|
| 1st determination | 59.0 $Co_2$ vol. per cent. |
| 2nd determination | 60.0 $Co_2$ vol. per cent. |
| Average determination | 59.5 $Co_2$ vol. per cent. |

A second blood sample was taken January 31, 1922 after 130 days of continuous milk feeding.

| | |
|---|---|
| 1st determination | 67.0 $Co_2$ vol. per cent. |
| 2nd determination | 67.0 $Co_2$ vol. per cent. |
| Average determination | 67.0 $Co_2$ vol. per cent. |

The normal alkaline reserve for a calf this age, according to Blatherwick (19) is 61.5 $Co_2$ vol. per cent. This phase of the experimental work was ended prematurely due to breaking of the only Van Slyke apparatus available for determining the alkaline reserve of the blood.

The feces of this calf were not firm and hard like those of the other calves receiving whole milk exclusively.

At the age of 168 days the calf frothed at the mouth and appeared sick. A red cell count of its blood gave a count of 11,000,000 per cc. The normal for a calf this age is 8,000,000.

The calf recovered from this sickness, and the symptoms of convulsions were not noticed until the age of 195 days, when it showed a hesitancy in drinking, followed by a chewing of the tongue and a slight choking in breathing. The first actual convulsions were observed the following day. They were not extremely vigorous however. These fits occurred quite frequently. The injection of 50 cc of ten per cent calcium chloride solution subcutaneously failed to relieve them, but caused an abscess to form at the place of injection. Cod liver oil and calcium carbonate were then added to the diet. A handful of alfalfa hay was offered to the calf to test its craving for roughage but was not as anxious for the hay as would be expected.

Cod liver oil and calcium carbonate in the diet stopped the convulsions completely. These supplements to the ration were fed for 28 days, during which the calf seemed entirely normal, showing not the least symptoms of nervousness. At the end of 28 days the calcium carbonate and cod liver oil were taken from the ration to determine if the convulsions would again appear. Five days following the removal of cod liver oil and calcium carbonate from the diet, the convulsions returned. The first one lasted an hour and a half. An injection of 150 cc of 5 per cent calcium lactate solution, which had been properly sterilized was made into the jugular vein. The calf had a convulsion during the injection, but not again show symptoms of convulsions, until the fifth day following this injection, altho every means were used to excite the animal which usually hastens the onset of convulsions.

On the fifth day after the injection of calcium lactate, the calf came down with convulsions and could not regain its feet until 150 cc of the calcium lactate solution had been injected into the blood. It was on its feet within an hour after the injection.

Death occurred the following day, but it had not experienced a convulsion since the calcium lactate injection the noon of the previous day.

A post-mortem examination found the stomach full of shavings, a slight hemorrhagic condition of the heart; one kidney congested and the other organs normal. Dr. Boyd was of the opinion that death was due to the shavings in the stomach.

Photographs are found on Plates 5, 6 and 7.

Calf V-10. The calf was placed on experiment September 23, 1921 and continued until death February 2, 1922. The ration consisted of whole milk and cod liver oil.

Observations of feeder and men in charge:

During the entire experiment the feces consisted of small, hard, round balls, much like that of sheep.

The calf at the age of 132 days, without a warning symptom came down and was unable to use its legs again. After it had been down three days, alkaline reserve determinations were made of the blood.

| | |
|---|---|
| 1st determination | 62.5 |
| 2nd determination | 63.5 |
| Average determination | 63.0 |

Normal according to Blatherwick (19) is 61.5. Immediately after removing the blood sample, 90 cc of calcium chloride was injected into the jugular vein, to determine if the trouble was due to a deficiency of calcium ions in the tissue. The following morning it was dead.

Post-mortem examination revealed a congested liver, inflamed gall bladder, marrow of the bones in a watery condition, and anemic conditions about the liver. The bones and joints in other

respects appeared normal.

Calf V-11. The calf was placed on this experiment at the age of 141 days. Its ration previous to this time consisted of skim milk, a grain mixture and alfalfa hay. The animal was changed from this ration to an exclusive whole milk diet, February 21, 1922, which it received until death.

Observations of feeder and men in charge:

The animal failed to gain materially in weight during the first five ten-day periods, after which it made fair gains until death.

At the age of 219 days, and after receiving whole milk exclusively for 78 days, it came down with convulsions from which it died.

Post-mortem examination revealed petechial hemorrhages in the muscles on the mycardium, and the same in the peritoneum. There was also a mild eneritis. The thymus glands were enlarged, particularily a lobe on the left side. The thyroids and parathyroid were normal. The stomach also appeared normal.

According to Dr. Fitch, the findings indicate a toxemia arising probably from the digestive tract.

## Discussion of Data

Every animal in these experiments receiving an exclusive milk diet came down with the characteristic convulsions which have been noted by others to follow the use of this ration. The evidence seems complete, that calves can not be grown from birth to maturity on milk alone.

The age at which the convulsions first appeared varied from 104 days to 195 days. The calves were apparently normal until a few days before the onset of convulsions. The weight ranged from 172 pounds to 312 pounds, and the height at withers varied from 95 per cent to 100 per cent normal at this time.

An attack of convulsions was usually preceded about three days by a highly nervous state, a chewing of the tongue and hesitancy in drinking. The appearance of convulsions was usually hastened by excitement, such as feeding or leading, and varied in duration from a few minutes to an hour and a half. Also some calves developed convulsions of greater intensity than others. These convulsions resemble very closely epileptic fits in humans. The spasms of whole milk calves also show considerable resemblance to spasmophilia, a similar condition in human infants.

### Lack of roughage as a cause of convulsions

As has already been stated, Eckles and Wilbur were unable to relieve convulsions in whole milk calves by adding bulk to the ration in the form of sawdust and filter paper. On the other hand, timothy hay brought about immediate relief. This curative effect may have been due to something other than the coarseness of the feed. The addition of either calcium carbonate or cod liver oil to the ration relieved and prevented the occurrence of convulsions which is

further evidence that the physiological failure of calves on whole milk is not due to a lack of roughage.

Vitamine deficiency as a cause of convulsions

The work of Eckles and Wilbur shows that convulsions in whole milk calves can not be relieved by feeding yeast as a source of vitamine "B" or orange juice as a source of vitamine "C". In this experiment, yeast was fed to calf V-6, resulting in a loss in weight of a pound a day and the convulsions were not relieved. These results eliminate the possibility of a deficiency of water soluble "B" or water soluble "C" in milk as the sole diet for calves.

The relation of calcium carbonate feeding to convulsions

Eckles and Wilbur relieved convulsions in four calves by feeding calcium carbonate. Calf V-5 failed to come down with convulsions up to the age of eight months on a diet of whole milk and calcium carbonate. At this age it was taken off the experiment apparently normal in every respect. In all probability the convulsions are due either to an insufficient amount of calcium in the ration or to an improper absorption of calcium.

Hughes and Cave of the Kansas Experiment Station raised two calves to one year of age on milk alone. These calves failed to show the symptoms of convulsions, which may have been due to the fact that they reached the critical period during the spring and summer when they were drinking water fairly heavily. The water at the Kansas Station contains 120 parts of calcium per million, while the water used in this experiment contained only 65.9 parts per million or approximately half as much; which suggests the possibility that the calves at the Kansas Experiment Station failed to come down with convulsions due to the large amount of calcium ingested in the water. These results point to a calcium deficiency in milk as the sole diet

for calves. However, milk has always been regarded as a high calcium food, since it contains .122 per cent of this element.

Improper absorption of calcium as the cause of convulsions

Calf V-6 came down with convulsions on a fat-free ration consisting of skim milk and starch, which indicates that the convulsions are not due to improper calcium absorption brought about by the fat forming insoluble soap with the calcium.

Acidosis or alkalosis as the cause of convulsions

The alkaline reserve of the blood which is a measure of acidosis or alkalosis was determined on the blood of calf V-8. Ninety one days after being placed on an exclusive whole milk ration the alkaline reserve was 59.5 $Co_2$ vol. per cent. The reading at the end of 130 days was 67 $Co_2$ vol. per cent. This phase of the experiment ended prematurely due to the breaking of the only available Van Slyke apparatus used for making the determination. The results are too meager to be considered seriously, however, they do not point to acidosis. On the other hand, the increase in the alkaline reserve, with continued whole milk feeding, suggests a possibility of alkalosis as the cause of convulsions in whole milk calves.

A lack of the antirachitic factor as the cause of convulsions

Calf V-6 came down with spasms which were cured by feeding cod liver oil. This calf gained 39 pounds the 30 days following the administration of cod liver oil. Calf V-10, which received a ration of whole milk and cod liver oil, did not come down with convulsions. According to recent investigations, cod liver oil contains the antirachitic vitamine which aids in calcium retention. This fourth vitamine has recently been named vitamine "D" by Dr. McCollum. Evidently the addition of this vitamine to the ration of whole milk calves brings about a greater calcium retention which prevents or cures

convulsions.

The possibility also was to be considered that the convulsions of whole milk calves are due to low calcium rickets, which are the rickets of tetany. This is further suggested by the close similarity of the symptoms of convulsions in whole milk calves and those in tetany. Both are relieved or prevented by either calcium feeding or cod liver oil therapy.

On the other hand, X -ray pictures taken of bones from Calf V-7, which died from convulsions, failed to show any evidence of rickets. According to some investigators, the presence of rickets is determined by the decalcification of the bones. The X -ray pictures on Plates 8 and 9 fail to show a decalcification of the bone.

Tetany in whole milk calves

The preventive and curative properties of cod liver oil and calcium carbonate, and the similarity of symptoms in tetany and convulsions in calves indicates very strongly that the two are identical. An intravenous injection of calcium lactate into a calf with convulsions produced immediate relief, lasting five days, which is further evidence that the condition developed in calves on an exclusive milk diet is tetany.

Tetany due to ion antagonism

The relief caused by the injection of calcium lactate may be due to ion antagonism. When sodium and potassium ions are found in the blood and tissues in a larger proportion than calcium and magnesium ions, irritability is produced known as tetany. The injection of calcium ions in the blood brings them up to normal number, relieving tetany. Calcium and magnesium ions repress irritability, while sodium and potassium ions produce irritability.

The lack of calcium ions in the blood of whole milk calves

may be due either to an insufficient amount of utilizable calcium in the ration or to improper calcium absorption. According to the most recent investigators, improper calcium absorption is due to a lack of the antirachitic vitamine in the diet.

Paralysis in calves fed whole milk plus cod liver oil

Two calves which were fed whole milk and cod liver oil, came down with a paralysis of the legs. This complication is entirely different from convulsions, and the cause is a mystery. Calcium chloride injected into the jugular vein did not relieve the condition. However, the feeding of calcium carbonate produced considerable improvement in calf V-6 which was down with paralysis. The calf was able to get up on its feet for about a half a minute at a time after two weeks of calcium carbonate feeding. The substitution of calcium phosphate for calcium carbonate brought the animal down again. Plates 3 and 4 show V-6 in this condition. Orange juice failed to remedy the condition in Calf V-10.

The results suggest a possible relationship between the paralysis and a lack of calcium carbonate in the diet. It is possible that the paralysis is due to a lack of iron absorption, and the calcium carbonate may have increased the absorption of iron thus causing an improvement.

The effect of an exclusive whole milk diet on older calves

Calf V-11 was placed on an exclusive whole milk ration at the age of 141 days. Previous to that time it had been receiving a ration ordinarily fed calves of the same age. After 78 days of whole milk feeding, the calf came down with convulsions and died, which shows that older calves placed on whole milk alone are also effected by the deficiency of milk.

## Conclusions

1. Calves can not be grown from birth to maturity on milk alone. At the age of from four to six months calves on such a ration develop nervous irritability, resulting in convulsions accompanied by a loss in weight; followed in a few weeks by death.

2. The condition resulting from feeding whole milk exclusively does not appear from the results of these experiments to be due to a lack of roughage in the ration. However, timothy hay added to the ration produced immediate relief. The curative property of the hay may have been some thing other than the roughage.

3. In all probability the nervous irritability produced in whole milk calves is not due to acidosis. The alkaline reserve of the blood of one calf increased with prolonged milk feeding.

4. In these experiments the nervous condition was relieved in every case by feeding calcium carbonate, where sufficient time was given. One calf fed calcium carbonate with whole milk failed to come down with convulsions.

5. The results of one calf fed skim milk and starch indicate that fat in the ration is not the causative factor in developing irritability.

6. Cod liver oil prevented the appearance of convulsions in one calf and cured the condition in another, but it did not prevent paralysis of the legs. Evidently some factor is needed in whole milk which is not found in cod liver oil.

7. The symptoms developed by calves on whole milk alone are identical with those described as tetany.

8. The tetany in a whole milk calf in this experiment was relieved by intravenous injections of calcium lactate. This relief

may have been due to the calcium ions of the injected solution overcoming the irritability produced by sodium and potassium ions in the blood and tissue.

9. A calf which had been fed on a ration ordinarily fed calves the same age, was placed on an exclusive whole milk diet at the age of five months, resulting in the appearance of convulsions in 78 days.

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# APPENDIX

Table 1 - Description of calves used in experiment.

| Calf | Sex | Age Beginning of Exp. | Age 1st Convulsion | Wt. 1st Convulsion | Height 1st Convulsion | Remarks |
|---|---|---|---|---|---|---|
| | | Days | Days | Lbs. | % Normal | |
| V-1 | Female | 24 | 120 | 21.6 | 96.2 | Death from convulsions. |
| V-2 | " | 24 | 117 | 22.2 | 101.0 | Dead - cause unknown. |
| V-3 | " | 24 | 104 | 17.6 | 97.0 | Fed complete diet. Recovered. |
| V-4 | " | 22 | 90 | 17.2 | 99.0 | Dead - cause unknown. |
| V-5 | Male | 39 | --- | ---- | ---- | Sold as herd sire. |
| V-6 | " | 17 | 184 | 27.1 | 95.0 | Unable to use leg muscles - died. |
| V-7 | " | 95 | 169 | 31.2 | 100.0 | Died from convulsions. |
| V-8 | " | 7 | 195 | 28.3 | 96.0 | Died due to shavings in stomach |
| V-9 | Female | 7 | --- | ---- | ---- | Died of pneumonia. Results not used in this thesis. |
| V-10 | " | 3 | --- | ---- | ---- | No convulsions. Came down unable to use leg muscles. Died. |
| V-11 | " | 141 | 219 | 33.5 | 100.0 | Died from convulsions. |

4-22-8M

Table 2 - Digestible crude protein and net energy values per 100 pounds for ruminants.#

| Feed | Digestible crude protein | Net Energy |
|---|---|---|
| | Lbs. | Therms. |
| Cows' milk (Whole) | 3.3 | 29.01 |
| Cows' milk (Centrifugal skimmed) | 3.6 | 14.31 |
| Starch | .0 | 100.07 |
| Sugar | .0 | 81.20 |
| [1] Cod liver oil | .0 | 422.20 |

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[1] Same as for butter fat.

Table 3 Calf V-5

Growth by weight and growth in height compared to normal.

| 10 day period | Age | Weight | Normal # Weight | Percent Normal Weight | Height | Normal # Height | Percent Normal Height |
|---|---|---|---|---|---|---|---|
| | Days | Lbs. | Lbs. | % | Cms. | Cms. | % |
| 1 | 48 | 114 | 142.6 | 79.9 | 73.4 | 78.36 | 93.7 |
| 2 | 58 | 123 | 154.6 | 79.6 | 77.0 | 81.64 | 94.3 |
| 3 | 68 | 139 | 168.4 | 82.5 | | | |
| 4 | 78 | 155 | 182.7 | 84.8 | | | |
| 5 | 88 | 170 | 197.0 | 86.3 | 82.3 | 86.48 | 95.2 |
| 6 | 98 | 179 | 213.0 | 84.0 | | | |
| 7 | 108 | 195 | 229.3 | 85.0 | | | |
| 8 | 118 | 216 | 245.6 | 87.9 | 87.6 | 91.65 | 95.6 |
| 9 | 128 | 231 | 263.1 | 87.8 | | | |
| 10 | 138 | 257 | 280.8 | 91.5 | | | |
| 11 | 148 | 279 | 298.4 | 93.5 | 94.6 | 96.2 | 98.3 |
| 12 | 158 | 295 | 314.5 | 93.8 | | | |
| 13 | 168 | 318 | 330.2 | 96.3 | | | |
| 14 | 178 | 336 | 345.9 | 97.1 | 99.2 | 100.61 | 98.6 |
| 15 | 188 | 347 | 359.6 | 96.5 | | | |
| 16 | 198 | 373 | 372.9 | 100.0 | | | |
| 17 | 208 | 386 | 386.3 | 99.92 | 101.8 | 103.79 | 97.2 |
| 18 | 218 | 404 | 398.6 | 101.3 | | | |
| 19 | 228 | 429 | 410.6 | 104.48 | | | |
| 20 | 238 | 447 | 422.6 | 105.77 | 106.1 | 106.89 | 99.3 |
| 21 | 248 | 452 | 435.93 | 103.43 | | | |

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Table 4 Calf V-5 Record of feed consumed.

Ration - Whole milk plus Ca $Co_3$

| 10 day period | Whole Milk | $CaCo_3$ | Nutrients required: Digestible Crude Protein | Nutrients required: Net Energy | Nutrients received: Digestible Crude Protein | Nutrients received: Net Energy | Gain in Weight |
|---|---|---|---|---|---|---|---|
| | Lbs. | Gms. | Lbs. | Therms. | Lbs. | Therms. | Lbs. |
| 1 | 105 | 360 | 0.420 | 3.22 | 0.347 | 3.05 | |
| 2 | 134 | 400 | 0.433 | 3.30 | 0.442 | 3.89 | 9 |
| 3 | 140 | 400 | 0.463 | 3.43 | 0.462 | 4.06 | 16 |
| 4 | 140 | 500 | 0.517 | 3.53 | 0.462 | 4.06 | 16 |
| 5 | 149 | 500 | 0.557 | 3.62 | 0.492 | 4.32 | 15 |
| 6 | 160 | 510 | 0.569 | 3.66 | 0.528 | 4.64 | 9 |
| 7 | 180 | 600 | 0.591 | 3.74 | 0.594 | 5.22 | 16 |
| 8 | 180 | 600 | 0.613 | 3.81 | 0.594 | 5.22 | 21 |
| 9 | 180 | 600 | 0.630 | 3.87 | 0.600 | 5.30 | 15 |
| 10 | 200 | 600 | 0.657 | 3.96 | 0.660 | 5.80 | 26 |
| 11 | 200 | 600 | 0.690 | 4.07 | 0.660 | 5.80 | 22 |
| 12 | 200 | 600 | 0.712 | 4.18 | 0.660 | 5.80 | 16 |
| 13 | 200 | 600 | 0.732 | 4.30 | 0.660 | 5.80 | 23 |
| 14 | 200 | 600 | 0.751 | 4.42 | 0.660 | 5.80 | 18 |
| 15 | 200 | 600 | 0.761 | 4.56 | 0.660 | 5.80 | 11 |
| 16 | 200 | 600 | 0.773 | 4.73 | 0.660 | 5.80 | 26 |
| 17 | 234 | 600 | 0.790 | 4.97 | 0.772 | 6.69 | 13 |
| 18 | 255 | 615 | 0.801 | 5.14 | 0.842 | 7.40 | 18 |
| 19 | 280 | 785 | 0.809 | 5.35 | 0.924 | 8.12 | 25 |
| 20 | 280 | 800 | 0.815 | 5.11 | 0.924 | 8.12 | 18 |
| 21 | 280 | 800 | 0.817 | 5.55 | 0.924 | 8.12 | 5 |

Table 5 Calf V-6

Growth by weight and growth in height compared to normal.

| 10 day period | Age | Weight | Normal Weight | Percent Normal Weight | Height | Normal Height | Percent Normal Height |
|---|---|---|---|---|---|---|---|
| | Days | Lbs. | Lbs. | % | Cms. | Cms. | % |
| 1 | 26 | 126 | 116.6 | 108.1 | | | |
| 2 | 36 | 146 | 128.2 | 113.9 | 81.5 | 77.84 | 105.4 |
| 3 | 46 | 161 | 140.2 | 114.8 | | | |
| 4 | 56 | 171 | 152.2 | 112.2 | | | |
| 5 | 66 | 182 | 165.6 | 109.9 | 84.3 | 92.96 | 101.6 |
| 6 | 76 | 183 | 179.9 | 101.7 | | | |
| 7 | 86 | 206 | 194.2 | 106.7 | | | |
| 8 | 96 | 212 | 209.8 | 101.0 | 89.5 | 87.84 | 101.9 |
| 9 | 106 | 221 | 226.1 | 97.7 | | | |
| 10 | 116 | 236 | 242.4 | 97.3 | | | |
| 11 | 126 | 252 | 259.6 | 97.0 | 91.5 | 92.9 | 98.5 |
| 12 | 136 | 267 | 277.3 | 96.3 | | | |
| 13 | 146 | 279 | 294.9 | 94.6 | | | |
| 14 | 156 | 281 | 311.4 | 90.2 | 93.9 | 97.38 | 96.4 |
| 15 | 166 | 281 | 327.1 | 85.9 | | | |
| 16 | 176 | 281 | 342.7 | 81.9 | | | |
| 17 | 186 | 271 | 357.0 | 75.9 | 96.5 | 101.52 | 95.0 |
| 18 | 196 | 278 | 370.29 | 75.1 | | | |
| 19 | 206 | 299 | 383.63 | 77.9 | | | |
| 20 | 216 | 310 | 396.20 | 78.24 | 96.4 | 104.62 | 92.14 |
| 21 | 226 | 309 | 408.20 | 73.23 | | | |
| 22 | 236 | | 420.20 | | | 107.56 | |
| 23 | 246 | | 433.19 | | | | |
| 24 | 256 | | 446.85 | | | | |
| 25 | 266 | 303 | 460.51 | 65.8 | | | |
| 26 | 276 | | 473.00 | | | 109.52 | |
| 27 | 286 | 294 | 484.66 | 60.66 | | | |
| 28 | 296 | 292 | 496.33 | 58.83 | | | |
| 29 | 306 | | 506.60 | | | 111.48 | |

Table 6 Calf V-6 Record of feed consumed.

Ration - Skimmilk plus starch.

| 10 day period | Skim Milk | Starch | Armsby Nutrients required: Digestible Crude Protein | Armsby Nutrients required: Net Energy | Nutrients received: Digestible Crude Protein | Nutrients received: Net Energy | Gain in Weight |
|---|---|---|---|---|---|---|---|
| | Lbs. | Lbs. Daily | Lbs. | Therms. | Lbs. | Therms. | Lbs. |
| 1 | | | .437 | 3.32 | 0.351 | 3.09 | |
| 2 | | | .453 | 3.41 | 0.442 | 3.89 | 20 |
| 3 | 45 | | .513 | 3.53 | 0.476 | 3.40 | 15 |
| 4 | 130 | | .566 | 3.61 | 0.501 | 2.15 | 10 |
| 5 | 149 | 1/3 | .574 | 3.65 | 0.536 | 2.51 | 11 |
| 6 | 160 | 1½ | .591 | 3.68 | 0.576 | 2.74 | 1 |
| 7 | 173 | 2 | .610 | 3.79 | 0.623 | 4.62 | 23 |
| 8 | 180 | 2 | .621 | 3.80 | 0.648 | 4.72 | 6 |
| 9 | 180 | 2 | .637 | 3.84 | 0.677 | 4.83 | 9 |
| 10 | 200 | 2 | .657 | 3.89 | 0.720 | 5.00 | 15 |
| 11 | 200 | 2 | .679 | 3.95 | 0.720 | 5.00 | 16 |
| 12 | 200 | 2 | .697 | 4.03 | 0.720 | 5.00 | 15 |
| 13 | 200 | 2 | .705 | 4.09 | 0.770 | 5.00 | 12 |
| 14 | 200 | 2 | .706 | 4.13 | 0.720 | 5.00 | 2 |
| 15 | 200 | 2 | .706 | 4.14 | 0.720 | 5.49 | 0 |
| 16 | 200 | 2 | .698 | 4.14 | 0.720 | 6.45 | 0 |
| 17 | 180 | 1.6 | .703 | 4.08 | 0.648 | 5.54 | 10 |
| 18 | 148 | .125 | .724 | 4.12 | 0.533 | 3.07 | 7 |
| 19 | 220 | 1 | .735 | 4.25 | 0.792 | 5.27 | 21 |
| 20 | 220 | 1 | .734 | 4.31 | 0.792 | 5.27 | 11 |
| 21 | 220 | 1 | .734 | 4.30 | 0.792 | 5.27 | 1 |
| 22 | 209 | 0.9 | .734 | 4.30 | 0.743 | 5.18 | |
| 23 | 195 | 1. | .734 | 4.30 | 0.695 | 5.14 | |
| 24 | 200 | 1 | .734 | 4.30 | 0.637 | 5.24 | |
| 25 | 205 | 1 | .728 | 4.27 | 0.738 | 4.64 | |
| 26 | 195 | 1 | .728 | 4.27 | 0.695 | 4.35 | |
| 27 | 200 | 1 | .719 | 4.22 | 0.706 | 4.82 | |
| 28 | 226 | 1 | .717 | 4.21 | 0.814 | 5.25 | |
| 29 | 217 | 0.9 | .717 | 4.21 | 0.781 | 4.01 | |
| 30 | 160 | | .717 | 4.21 | 0.576 | 2.78 | |

Table 7 Calf V-7

Growth by weight and growth in height compared to normal.

| 10 day period | Age | Weight | Normal Weight | Percent Normal Weight | Height | Normal Height | Percent Normal Height |
|---|---|---|---|---|---|---|---|
| | Days | Lbs. | Lbs. | % | Cms. | Cms. | % |
| 1 (7 da) | 101 | 220 | 217.96 | 101.03 | 91.4 | 87.66 | 104.23 |
| 2 | 111 | 227 | 234.29 | 96.9 | | | |
| 3 | 121 | 236 | 250.08 | 94.37 | 93.7 | 92.15 | 101.67 |
| 4 | 131 | 244 | 268.43 | 90.9 | | | |
| 5 | 141 | 262 | 286.1 | 91.6 | | | |
| 6 | 151 | 278 | 303.56 | 91.2 | 96.7 | 96.64 | 100.06 |
| 7 | 161 | 305 | 319.23 | 95.54 | | | |
| 8 | 171 | 312 | 334.9 | 93.2 | | | |

Table 8 Calf V-7 Record of feed consumed.

Ration - Whole milk alone.

| 10 day period | Whole Milk | Nutrients required (Armsby) | | Nutrients received | | Gain in Weight |
|---|---|---|---|---|---|---|
| | | Digestible Crude Protein | Net Energy | Digestible Crude Protein | Net Energy | |
| | Lbs. | Lbs. | Therms. | Lbs. | Therms. | Lbs. |
| 1 (7 da) | 92 | 0.625 | 3.85 | 0.432 | 3.80 | 5 |
| 2 | 154 | 0.634 | 3.88 | 0.508 | 4.47 | 7 |
| 3 | 180 | 0.648 | 3.93 | 0.594 | 5.22 | 9 |
| 4 | 200 | 0.657 | 3.96 | 0.660 | 5.80 | 8 |
| 5 | 200 | 0.682 | 4.04 | 0.660 | 5.80 | 18 |
| 6 | 212 | 0.703 | 4.12 | 0.700 | 6.15 | 16 |
| 7 | 222 | 0.730 | 4.28 | 0.733 | 6.44 | 27 |
| 8 | 240 | 0.737 | 4.33 | 0.792 | 6.96 | 7 |

Started feeding Ca $Co_3$ two days before death.

Table 9 Calf V-8

Growth by weight and growth in height compared to normal.

| 10 day period | Age | Weight | Normal Weight | Percent Normal Weight | Height | Normal Height | Percent Normal Height |
|---|---|---|---|---|---|---|---|
| | Days | Lbs. | Lbs. | % | Cms. | Cms. | % |
| 1(7da) | 13 | 88 | 103.43 | 85.08 | 69.3 | 72.96 | 94.9 |
| 2 | 23 | 96 | 113.76 | 84.08 | | | |
| 3 | 33 | 104 | 124.6 | 83.46 | 74.4 | 77.32 | 96.22 |
| 4 | 43 | 111 | 136.6 | 81.40 | | | |
| 5 | 53 | 120 | 148.6 | 80.75 | | | |
| 6 | 63 | 134 | 101.3 | 83.07 | 77.4 | 82.48 | 93.84 |
| 7 | 73 | 152 | 175.63 | 86.55 | | | |
| 8 | 83 | 165 | 189.96 | 86.86 | | | |
| 9 | 93 | 170 | 204.90 | 82.97 | 83.3 | 87.32 | 95.4 |
| 10 | 103 | 189 | 221.23 | 85.43 | | | |
| 11 | 113 | 200 | 237.56 | 84.18 | | | |
| 12 | 123 | 222 | 254.30 | 87.30 | 87.5 | 92.45 | 94.64 |
| 13 | 133 | 238 | 271.96 | 87.51 | | | |
| 14 | 143 | 256 | 289.63 | 88.38 | | | |
| 15 | 153 | 265 | 306.70 | 86.40 | 93.6 | 96.94 | 96.55 |
| 16 | 163 | 269 | 322.36 | 83.44 | | | |
| 17 | 173 | 274 | 338.03 | 81.05 | | | |
| 18 | 183 | 277 | 352.99 | 78.47 | 96.4 | 101.21 | 95.24 |
| 19 | 193 | 283 | 366.29 | 77.26 | | | |
| 20 | 203 | 287 | 379.63 | 75.59 | | | |
| 21 | 213 | 283 | 392.60 | 72.08 | 96.8 | 96.8 | 92.8 |
| 22 | 223 | 290 | 404.60 | 71.65 | | | |
| 23 | 233 | 290 | 416.60 | 69.61 | | | |
| 24 | 243 | 282 | 429.10 | 65.72 | 97.1 | 107.3 | 90.5 |

Table 10 Calf V-8 Record of feed consumed.

Ration - Whole milk alone.

| 10 day period | Whole Milk | Armsby Nutrients required: Digestible Crude Protein | Armsby Nutrients required: Net Energy | Nutrients received: Digestible Crude Protein | Nutrients received: Net Energy | Gain in Weight |
|---|---|---|---|---|---|---|
| | Lbs. | Lbs. | Therms. | Lbs. | Therms | Lbs. |
| 1 (7 da) | 62 | | | 0.297 | 2.61 | 4 |
| 2 | 86 | | | 0.284 | 2.49 | 8 |
| 3 | 92 | 0.406 | 3.13 | 0.304 | 2.67 | 8 |
| 4 | 100 | 0.416 | 3.19 | 0.330 | 2.90 | 7 |
| 5 | 101 | 0.428 | 3.27 | 0.363 | 3.19 | 9 |
| 6 | 113 | 0.448 | 3.39 | 0.373 | 3.28 | 14 |
| 7 | 131 | 0.507 | 3.51 | 0.432 | 3.80 | 18 |
| 8 | 140 | 0.550 | 3.60 | 0.462 | 4.06 | 15 |
| 9 | 152 | 0.557 | 3.62 | 0.502 | 4.41 | 5 |
| 10 | 156 | 0.583 | 3.71 | 0.515 | 4.53 | 19 |
| 11 | 162 | 0.598 | 3.76 | 0.535 | 4.70 | 11 |
| 12 | 173 | 0.628 | 3.86 | 0.571 | 5.02 | 22 |
| 13 | 180 | 0.649 | 3.93 | 0.594 | 5.22 | 16 |
| 14 | 180 | 0.672 | 4.01 | 0.594 | 5.22 | 18 |
| 15 | 180 | 0.686 | 4.05 | 0.594 | 5.22 | 9 |
| 16 | 180 | 0.691 | 4.07 | 0.594 | 5.22 | 4 |
| 17 | 184 | 0.698 | 4.09 | 0.607 | 5.33 | 5 |
| 18 | 200 | 0.702 | 4.11 | 0.660 | 5.80 | 3 |
| 19 | 200 | 0.708 | 4.15 | 0.660 | 5.80 | 7 |
| 20 | 199 | 0.713 | 4.18 | 0.567 | 5.77 | 4 |
| 21 | 210 | 0.708 | 4.15 | 0.693 | 6.09 | 4 |
| 22 | 210 | 0.715 | 4.19 | 0.693 | 6.09 | 7 |
| 23 | 194 | 0.715 | 4.19 | 0.639 | 5.61 | 0 |
| 24 | 160 | 0.707 | 4.15 | 0.528 | 4.64 | 8 |

Periods 21-24 fed Ca $Co_3$ and cod liver oil.

Periods 16-26 sugar was fed.

Period 17 - 600 grams dried yeast fed.

Period 18 until death - 560 grams cod liver oil fed per period.

Periods 22 until death - Ca $Co_3$ and $Co_3$ $(Co)_2$ were fed.

Period 24 - 250 cc of orange juice fed.

Table 11 Calf V-10

Growth by weight and growth in height compared to normal.

| 10 day period | Age | Weight | Normal Weight | Percent Normal Weight | Height | Normal Height | Percent Normal Height |
|---|---|---|---|---|---|---|---|
| | Days | Lbs. | Lbs. | % | Cms. | Cms. | % |
| 1 (7 da) | 9 | 90 | 99.30 | 90.63 | 72.7 | 72.3 | 100.55 |
| 2 | 19 | 104 | 109.63 | 94.84 | | | |
| 3 | 29 | 109 | 119.96 | 91.01 | 76.5 | 76.61 | 99.95 |
| 4 | 39 | 116 | 131.80 | 88.01 | | | |
| 5 | 49 | 121 | 143.80 | 84.14 | | | |
| 6 | 59 | 140 | 155.80 | 89.86 | 80.0 | 81.82 | 97.78 |
| 7 | 69 | 153 | 169.9 | 90.05 | | | |
| 8 | 79 | 165 | 184.23 | 89.56 | | | |
| 9 | 89 | 172 | 198.55 | 86.63 | 86.1 | 86.64 | 99.38 |
| 10 | 99 | 195 | 214.7 | 90.82 | | | |
| 11 | 109 | 194 | 231.03 | 83.92 | | | |
| 12 | 119 | 210 | 247.35 | 84.81 | 90.3 | 91.82 | 98.06 |
| 13 | 129 | 227 | 264.90 | 85.69 | | | |

Table 12 Calf V-10 Record of feed consumed.

Ration - Whole milk plus cod liver oil.

| 10 day period | Whole Milk | Cod Liver Oil | Armsby Nutrients required: Digestible Crude Protein | Armsby Nutrients required: Net Energy | Nutrients received: Digestible Crude Protein | Nutrients received: Net Energy | Gain in Weight |
|---|---|---|---|---|---|---|---|
| | Lbs. | Oz. | Lbs. | Therms. | Lbs. | Therms. | Lbs. |
| 1(7da) | 64 | | | | 0.297 | 2.61 | 6 |
| 2 | 86 | 14 | 0.406 | 3.13 | 0.284 | 2.49 | 10 |
| 3 | 92 | 138 | 0.413 | 3.18 | 0.304 | 2.67 | 5 |
| 4 | 100 | 220 | 0.423 | 3.24 | 0.330 | 3.10 | 7 |
| 5 | 100 | 280 | 0.430 | 3.28 | 0.330 | 3.13 | 5 |
| 6 | 113 | 280 | 0.467 | 3.43 | 0.373 | 3.53 | 19 |
| 7 | 131 | 336 | 0.510 | 3.52 | 0.432 | 4.10 | 13 |
| 8 | 140 | 555 | 0.550 | 3.60 | 0.462 | 4.55 | 12 |
| 9 | 140 | 555 | 0.560 | 3.63 | 0.462 | 4.55 | 7 |
| 10 | 157 | 555 | 0.591 | 3.74 | 0.518 | 5.05 | 23 |
| 11 | 162 | 555 | 0.589 | 3.73 | 0.534 | 5.19 | 1 |
| 12 | 173 | 555 | 0.611 | 3.80 | 0.567 | 5.48 | 16 |
| 13 | 180 | 555 | 0.634 | 3.88 | 0.594 | 5.71 | 17 |

Orange juice was fed four days previous to death.

Table 13 Calf V-11

Growth by weight and growth in height compared to normal.

| 10 day period | Age | Weight | Normal Weight | Percent Normal Weight | Height | Normal Height | Percent Normal Height |
|---|---|---|---|---|---|---|---|
| | Days | Lbs. | Lbs. | % | Cms. | Cms. | % |
| 1 | 148 | 270 | 298.46 | 90.47 | 96.1 | 101.2 | |
| 2 | 158 | 276 | 314.53 | 87.75 | | | |
| 3 | 168 | 282 | 330.20 | 85.40 | 96.6 | 99.14 | 97.44 |
| 4 | 178 | 276 | 345.86 | 79.80 | | | |
| 5 | 188 | 299 | 359.64 | 83.13 | | | |
| 6 | 198 | 321 | 372.96 | 86.06 | 102.4 | 102.76 | 99.65 |
| 7 | 208 | 324 | 386.29 | 83.87 | | | |
| 8 | 218 | 335 | 398.6 | 84.04 | | | |

Table 14 Calf V-11 Record of feed consumed.

Ration - Whole milk alone.

| 10 day period | Whole Milk | Armsby Nutrients required: Digestible Crude Protein | Armsby Nutrients required: Net Energy | Nutrients received: Digestible Crude Protein | Nutrients received: Net Energy | Gain in Weight |
|---|---|---|---|---|---|---|
| | Lbs. | Lbs. | Therms. | Lbs. | Therms. | Lbs. |
| 1 (7 da) | 140 | .693 | 4.08 | .660 | 5.80 | 0 |
| 2 | 200 | .701 | 4.11 | .660 | 5.80 | 6 |
| 3 | 200 | .707 | 4.15 | .660 | 5.80 | 6 |
| 4 | 220 | .701 | 4.11 | .726 | 6.38 | 6 |
| 5 | 239 | .724 | 4.25 | .772 | 6.78 | 23 |
| 6 | 310 | .746 | 4.38 | 1.023 | 8.99 | 22 |
| 7 | 280 | .749 | 4.40 | .924 | 8.12 | 3 |
| 8 | 280 | .757 | 4.50 | .929 | 8.12 | 11 |

P L A T E 1


Calf V-5

Age 215 days

Ration - Whole milk plus Ca $Co_3$

Weight compared to normal - 101 per cent

Height compared to normal - 98 per cent

4-22-6M

# P L A T E 2

Calf V-6

Age 193 days

Ration - Skim milk, starch and cod liver oil

Weight compared to normal - 75 per cent

Height compared to normal - 95 per cent

After being cured of convulsions by feeding cod liver oil.

# P L A T E 3


Calf V-6

Side View

Age 287 days

Ration - Skim milk, starch, Ca $Co_3$ and $Ca_3(Po_4)_2$

Legs paralyzed - Appears contented

Has not walked for 53 days.

4-22-8M

# P L A T E 4


Calf V-6

Front View

Taken the same date as in Plate 3.

# P L A T E 5

Calf V-8

Age 104 days

Ration - Whole milk

Weight compared to normal - 86 per cent

Height compared to normal - 95 per cent

# P L A T E 6


Calf V-8

Age 192 days

Ration - Whole milk

Three days before first convulsion.

4-22-6M

# PLATE 7

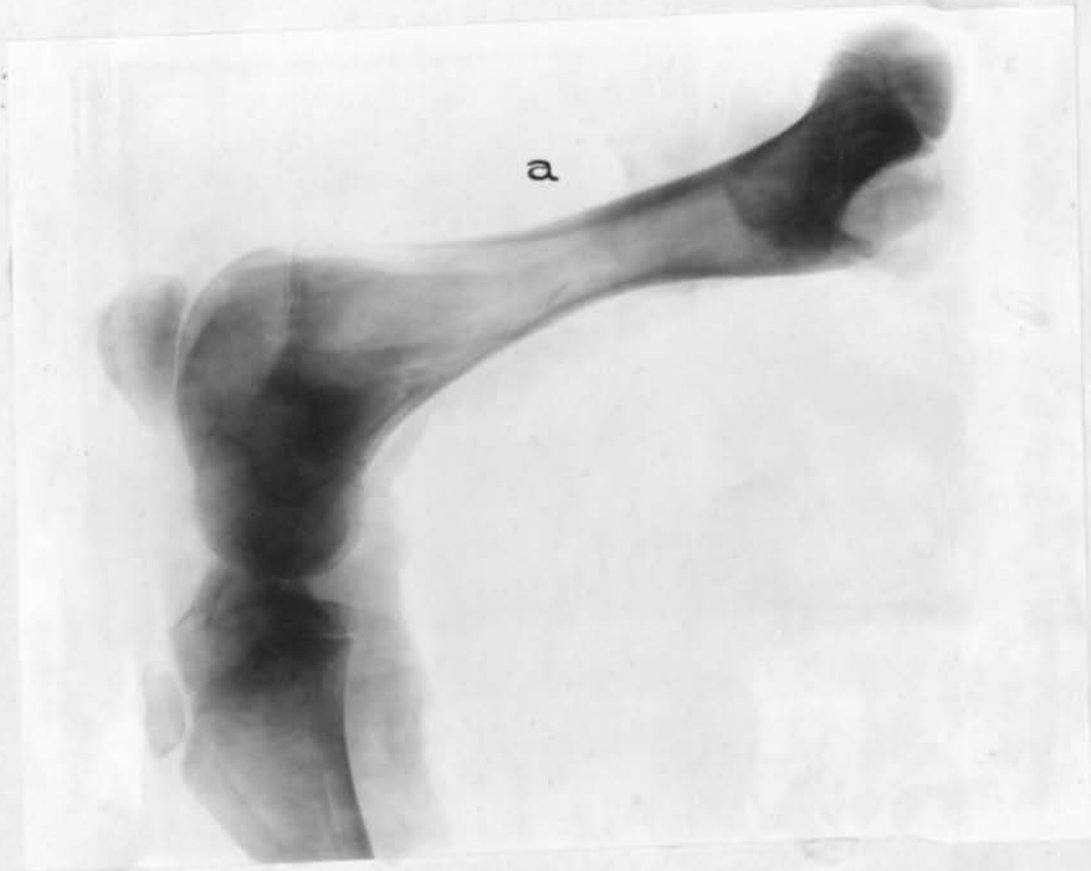

Calf V-8

Age 224 days

After being cured of convulsions by feeding

$Ca\ Co_3$ and cod liver oil.

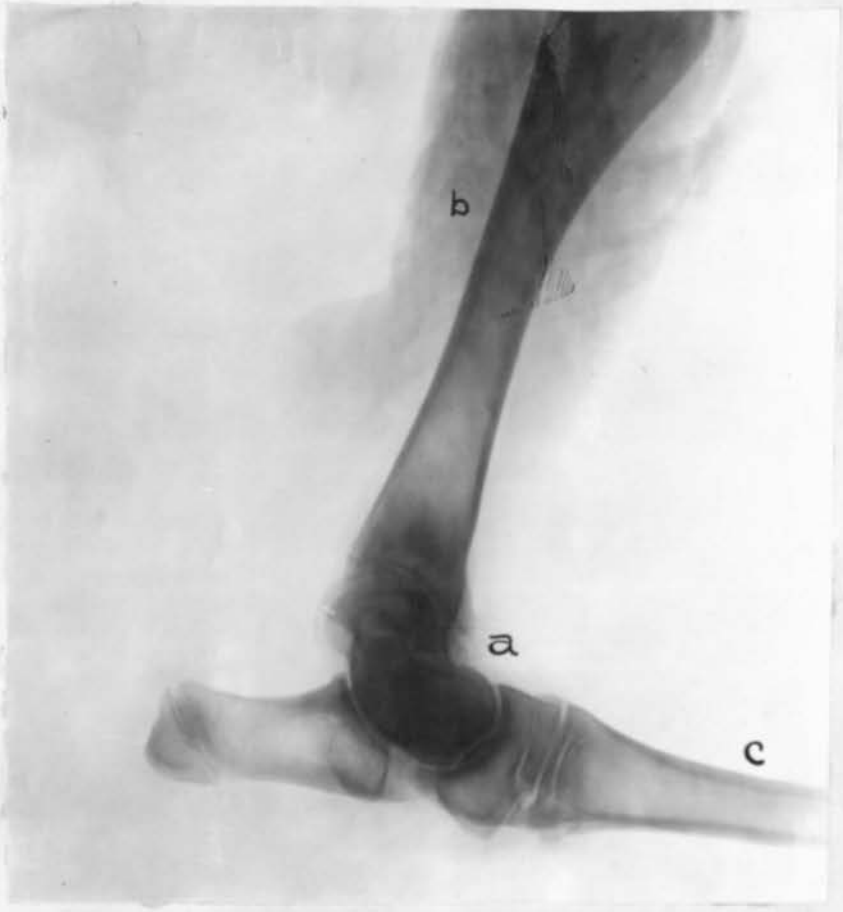
PLATE 8




(a) X-ray picture of femur - from Calf V-7 after death from convulsions, showing very little decalcification. No indications of rickets.

4-22-8M

# PLATE 9




X-ray picture of (a) Hock joint abnormally flexed so as to get on plate. (b) tibia, (c) metatarsis, showing but very little decalcification. No indications of rickets.

4-22-8M