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To the Graduate Council:

I am submitting herewith a thesis written by Elliott Darby Adams, Jr. entitled "The Use of X-Ray Techniques in Dwarfism Studies in Beef Cattle." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Husbandry.

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**THE USE OF X-RAY TECHNIQUES IN DWARFISM
STUDIES IN BEEF CATTLE**

A THESIS

**Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science**

by

Elliott Darby Adams, Jr.

March 1956

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E. D. Adams, Jr.

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CHAPTER I

INTRODUCTION AND PURPOSE

The increasing frequency with which hereditary dwarfism has been occurring in the three major breeds of beef cattle has caused great concern in the beef cattle industry. Several different hereditary types of these "dwarfs", or "cretins", have been reported by various workers in this field, but the rarity of most makes them of minor economic importance. However, one type has become frequent enough that it is currently of considerable economic significance. This kind of dwarfism is commonly called the "snorter" type because of the labored breathing of most afflicted animals. Such dwarfs generally have a short life expectancy. Many die at birth and others succumb to bloat and other metabolic disturbances with increased age. If "snorter" dwarfs reach maturity, they produce undesirable carcasses which are lacking in size and finish.

This "snorter" type of dwarfism is present in the Angus, Hereford and Shorthorn breeds. To date, the purebred breeder has probably suffered the most drastic economic setback, as the occurrence of dwarfs in his herd lowers his sale of breeding cattle. However, quite a few commercial herds have also produced dwarfs, resulting in dollar loss. The percentage of dwarfs found in all of the beef breeds is a matter of speculation, but the frequency of the condition is increasing.

Research indicates that the "snorter" type of dwarf results from the effect of a single autosomal recessive gene in the homozygous condition. On this assumption, normal appearing, but heterozygous, sires and dams transmit this gene to their offspring in a simple Mendelian

manner, producing three kinds of cattle when heterozygous parents are mated: clean or non-carrier (phenotypically normal and genotypically homozygous for the dominant normal allele), carrier (phenotypically normal but genotypically heterozygous) and dwarf (phenotypically dwarf and genotypically homozygous for the recessive gene). The occurrence of a dwarf is generally detected by visual inspection in which case both the sire and dam are proven carriers. However, the probability of a dwarf's being produced from the mating of two carrier parents is 25 percent, which leaves a 75 percent possibility that both would be undetected.

A carrier bull mated to a clean cow herd sires replacement offspring in a ratio of 50 percent clean and 50 percent carrier. Since dwarfs do not go into the breeding herd as replacements, the incidence of dwarfism would eventually become stabilized in an unselected cattle herd. For example, Lush and Hazel of Iowa State College (1954) state that the dwarf population would level off at about 14.6 percent if all of the bulls mated every generation to an unselected cow herd were carriers. If 60 or 40 percent of the bulls mated to unselected cows were carriers, the occurrence of dwarfs would level off around 6.1 and 3.0 percent, respectively. However, there may appear a wide variation in the actual occurrence of dwarfs from year to year due to chance.

If the heterozygous genotype of bulls could be distinguished phenotypically and only clean sires selected and used, it would be possible to ultimately eliminate carrier cattle.

Purpose

The increasing frequency of dwarfs in recent years seems to indicate that carrier individuals have been favored in the selection of breeding stock, although experimental evidence to confirm this is lacking. The cause of this trend in selection is not known; therefore, many recent research investigations have been conducted to try to find methods to detect carrier animals. One method for the identification of dwarf carriers proposed by L. N. Hazel of Iowa State College involves taking X-ray pictures of the lumbar vertebrae of young calves to be used in classifying the animals into non-carrier, carrier and dwarf types on the basis of the presence and/or absence of certain vertebral abnormalities.

In 1954, the University of Tennessee, in co-operation with Iowa State College, began research on the problem of methods of distinguishing between non-carrier and carrier cattle. High (1955) presented results of the first year's work in which three known carrier bulls were mated to cow herds thought to be relatively free of the dwarf gene. The progeny were X-rayed and classified into non-carrier, carrier and dwarf types on the basis of lumbar X-ray exposures. He reported that the ratio of non-carrier to carrier in the progeny of one bull deviated somewhat from the expected 50:50 ratio, but was well within the limits of chance. The ratios (carriers to non-carriers) among the progeny of the other two bulls were approximately the same as expected. High (1955) also presented results of a study of the relationship of various body measurements to genotypes for bovine dwarfism as

estimated from X-rays of the lumbar vertebrae. The results of this study indicated that presumed carrier animals (by X-ray determination) exhibited superiority in some desirable beef cattle characteristics.

The purpose of this paper is to present the results of further studies on the value and interpretation of the X-ray technique in the identification of carriers of the dwarfism gene.

CHAPTER II

REVIEW OF LITERATURE

An eight-months-old Hereford calf, the result of mating a purebred bull and a good grade Hereford cow, caught the attention of research personnel at Oklahoma A & M College in 1923. Characterized by a general dwarf-like condition - short and irregularly curved legs, abnormally large joints, short and thickened face, and a nervous disposition - this calf provided the first reference to hereditary bovine dwarfism in beef cattle by American workers. Craft and Orr (1924) reported that only slight improvement was made by the calf during a two-months observation period. Slaughter data on the then ten-months-old, 330-pound calf revealed no abnormalities of the viscera and many of the glands. However, the pituitary was only about one-half developed, the thyroids and parathyroids were about one-fifth normal size, and the bones lacked normal firmness. Thus, disregarding hereditary factors, it was concluded that insufficiency of particular endocrine secretions, primarily of the abnormal thyroid gland, was the immediate cause of cretinism.

Lush (1930) reported on another type of dwarfism exhibited by Hereford cattle of west central Texas. No signs of bull-dog heads, enlarged joints, or other bone malformations indicating a hypothyroid condition were found. Instead, the bodies and heads were equal in size to those of normal purebred Herefords. The only difference from normal Herefords was that in mature cattle the legs were four to six inches shorter. These "duck-legged" cattle were the result of continued outcrossing of herds to purebred Hereford bulls with the occasional use

of a short-legged grade bull accompanied by selection of short-legged females. Such a breeding plan produced a large percentage of "duck-leg" calves, although some had legs of normal length. Thus, it was concluded that this character is inherited in simple Mendelian manner and produced by the action of a single dominant gene.

Research has been intensified through the years as variations from phenotypically normal calves have appeared. With these increased efforts, several types of hereditary dwarfism have been encountered in the three major beef breeds, Hereford, Shorthorn and Angus. The difference between types has been in the distinct morphological characteristics of each.

Stonaker and Tom (1944) reported an extreme degree of compactness in three purebred Shorthorn herds located in Colorado, Nebraska and Kansas. Body type variation in these herds was not continuous, but was easily divided into two distinguishable groups. Compared with the larger, more upstanding cattle of the "standard" group, the "compacts" were small, short-legged, thick animals that found favor with many breeders. No compact individual resulted from standard X standard matings. Using compact bulls for concentration, the degree of compactness noted from compact X standard matings was equal to that of compact X compact matings. From the observed ratios of the various types in unselected calf crops, it was concluded that the character is the result of a single dominant gene.

Recently, Stonaker (1954) reported the "comprest" type in Hereford cattle to be a similar condition caused by an incompletely domi-

nant gene. In the homozygous dominant condition of the gene an extreme type of dwarfism resulted, but did not appear to be as pronounced in Herefords as in Shorthorns. A high percentage of such dwarfs were crippled or "crooked-legged". Research conducted in Oklahoma by Chambers et al. (1954) indicated that either the genes responsible for dwarfism in "comprest" Herefords and the "snorter" dwarfism of conventional Herefords and Angus were allelomorphic or the "comprest" cattle in their test carried a high frequency of the recessive "snorter" dwarf gene found in non-comprest cattle.

Baker et al. (1950) reported that "stumpy" Shorthorn calves began appearing in some purebred herds in Nebraska about 1940. They were characterized by a curly haircoat and small switch, which made them easily distinguishable at birth, achondroplasia, particularly in the bowed forelegs, and an unthriftiness which increased with age. These calves survived and reproduced despite their lack of size and vigor. The result of intensive line breeding, "stumpy" calves of both sexes were observed in an almost perfect 3:1 ratio (normal:stumpy). Conclusions thus indicated this abnormality to be non-lethal, non-sex-linked and caused by a single autosomal recessive gene.

Another type of dwarfism syndrome in Angus cattle was reported by Baker et al. (1951). The observed ratio of normal to dwarf in the offspring, representing both sexes, from proven heterozygous matings coincided with the single recessive gene hypothesis. Not readily distinguishable from normalcy at birth, these Angus calves exhibited compact, low-set, thick bodies with short, wide heads at various ages up

to three months of age. At early ages they generally possessed a higher degree of fatness than did the "stumpy" Shorthorns of comparable age. However, a noted loss of the early initial high finish occurred with increasing age. Also, the head became relatively longer and narrower than at an earlier age.

Elings (1953) mentioned that there appeared to be six or more simple recessive genes causing dwarfism among the three major beef breeds. Most of these, according to Lush and Hazel (1954), are so rare that they have little economic importance. However, they stressed that one particular type of inherited dwarfism, which they termed "snorter", has become frequent enough in beef cattle to be an economic problem.

Recent studies have thus been directed primarily toward the type of hereditary dwarfism first reported in Hereford cattle by Craft and Orr (1924). Recent research by Johnson et al. (1950), Gregory et al. (1951), Lindley (1951), Elings (1953), Lush and Hazel (1954) and Pahnish et al. (1954) verified the earlier work. With no elaboration, Gregory et al. (1953) suggested that the "snorter" type of dwarfism was also present in the Angus and Shorthorn breeds. High (1955) stated that cross-bred dwarfs from Hereford-Angus matings gave evidence that this dwarfism was conditioned by the same gene in both breeds.

Investigators noted that many of these dwarfs died previous to, during, or shortly after birth. However, in the case of survival, many morphological manifestations of this dwarfism syndrome were exhibited in varying degrees and did not always persist for an extended period

of time. There are conflicting reports as to the age these characteristics were first exhibited by afflicted animals.

Johnson et al. (1950) reported that the body dimensions of newborn dwarf Hereford calves resembled normal cattle with the exception that the dwarfs were slightly wider and blockier than normal calves. Possession of wide, mature-looking heads with bulging foreheads enabled easy identification at birth. Other workers report, however, that these individuals first begin to exhibit dwarf traits from a month to four months of age.

Lindley (1951) and Pahnish et al. (1954) found the birth weight of dwarf calves to be variable. Some weights were equal to those of normal calves. Johnson et al. (1950) indicated that this normal weight of some dwarfs combined with wide heads and blockiness of the body increased calving difficulties, especially with first calf heifers. In the case of dwarf dams, Lindley (1951) and Stonaker (1954) said caesarian section removal was generally necessary for survival of both dam and offspring. Lindley (1951) and Pahnish et al. (1954) noted bulging eyes and a glassy stare in dwarf calves at birth, but these became less apparent with age and approached normality after one month of age.

Malocclusion, caused by an undershot jaw, first observed by Johnson et al. (1950) and later by Lindley (1951) and Elings (1953), was generally found to be present at birth and persistent throughout life. In contrast, the disproportion exhibited at birth by normal calves adjusted to normality with increased age. Elings (1953) des-

cribed a continuous tongue protrusion that was commonly observed in newborn dwarfs during the first few weeks of life. Pahnish et al. (1954) found an adjustment of this latter trait to normal within two months.

Pahnish et al. (1954) and other recent investigators found afflicted animals exhibiting muscular weakness, faulty equilibrium and in-co-ordination at birth. These characteristics often resulted in the inability of the dwarf to stand or to nurse its dam without assistance. Some extreme cases had to be sacrificed, while others progressively gained in strength with proper nourishment. However, these traits were persistent throughout life, though variable in the degree of expression. Hindquarters not tracking with the front as observed by Elings (1953) was evidenced only during rapid motion. Knuckled over pasterns and complete cripples were rare, but an autopsy of one such dwarf by Johnson et al. (1950) revealed contraction of the flexor tendons of the legs.

Gregory et al. (1951) reported that dwarfs of all ages had a shortening of the long bones. By periodic measurements and general observations from birth to maturity, Pahnish et al. (1954) found that male dwarf calves exhibited proportionately short forecannons which tended to persist throughout life.

Although dwarf calves do not always deviated appreciably from normal body proportions at very young ages, several investigators suggested that the frequent occurrence of these traits might enable early diagnosis. However, Pahnish et al. (1954) stressed that some

manifestations of dwarfism were not commonly exhibited at birth but were developed and maintained during the postnatal period.

With the birth weights of dwarf and normal calves sometimes comparable, the midget appearance was not always immediately evident. All workers were in agreement, however, that the decreased growth rate of dwarf individuals soon produced pronounced size and weight differences. Pahnish et al. (1954) noted these differences within three months of age. Physiological studies by Carroll et al. (1951) to determine the cause of this stunted growth indicated that the pituitary glands were deficient in thyrotropic hormone. Additional studies revealed that growth and gonad stimulating hormones were present. Although specific endocrine interrelationships of dwarfs were not determined, these workers suggested that cretin characteristics were understandable if a hypothyroid condition was involved.

Although newborn dwarfs usually had or soon attained a mature blocky appearance from a side view, it was stressed that they soon developed a narrow back and loin. This was emphasized by an enlarged abdomen and the inclination to bloat with increasing age. Both sporadic and chronic cases of bloat were observed, and it was generally reported that this was frequently the cause of death. Pahnish et al. (1954) found relative body narrowness generally appeared at about one month of age and bloating became evident at thirty to sixty days. Upon autopsy of a dwarf calf, Johnson et al. (1950) found a bloated rumen to be overly distended but exhibiting no gross lesions.

Investigators reported that as the pot-belly and bloating

characteristics of dwarfs developed, breathing became heavy and forced both at rest and following exertion. Once developed, this respiratory defect persisted causing adoption of the term "snorter dwarf". Post-mortem examination by Pahnish et al. (1954) revealed no respiratory tract obstruction, and it was concluded that bloating was a contributing factor but not the basic cause of death.

All investigators noted a general lack of thriftiness shown by dwarf calves beginning at two to three months of age and persisting with age. Pahnish et al. (1954) noted that two-year-old dwarfs of both sexes possessed the ability to attain a fair degree of condition if allowed an unrestricted ration of alfalfa.

Although defects generally cause early death of dwarfs, a few reach the age of sexual maturity and reproduction. The gonadotropic hormone was found to be present in all dwarfs autopsied by Carroll et al. (1951). Lindley (1951) noted that the ovaries of dwarfs were apparently normal, and many workers have observed normal heat periods in females. Johnson et al. (1950) and Lindley (1951) found very few spermatozoa present in the tubules of the testicles and the genital tract of two-year-old males. Difficulties in obtaining conception in dwarf matings have been reported by Pahnish et al. (1954) and Lush and Hazel (1954).

Lush and Hazel (1954) described the inheritance of the "snorter" type of dwarfism. Designating the normal development gene as N and the allele for dwarfism as n, they found cattle to be of only three kinds: homozygous true normals (NN); heterozygous normal-appearing carriers

(Nn); and homozygous dwarfs (nn). Since a parent produces a germ cell containing only one gene of each set and since both sexes are equal in their ability of transmittance, six types of matings and their resulting offspring were observed: (1) NN X NN produced all NN normals; (2) NN X Nn produced one-half NN and one-half Nn carriers; (3) Nn X Nn produced about one-fourth NN, one-half Nn, and one-fourth nn dwarfs; (4) NN X nn produced all Nn carriers; (5) Nn X nn produced about one-half Nn carriers and one-half nn dwarfs; and (6) nn X nn produced all nn dwarfs. Type 1 mating has been the desirable one since no carriers or dwarfs resulted. Type 2 has caused the introduction of dwarfism into herds. Type 3 has produced dwarf offspring. Matings of types 4, 5 and 6, using dwarf parents, have been used only for experimental purposes.

They stated that a single pair of genes must have been responsible for this type of dwarfism, or else the offspring from proven carrier matings would not have adhered as closely to the expected ratio of three normals to one dwarf.

Lush and Hazel (1954) also noted that the "snorter" type of dwarfism was genetically different from the fairly common "comprest" or "compact" type. The "snorter" type was recessive, and the dwarfs were seriously handicapped. The compressed or compact type of dwarfism was dominant, or at least semi-dominant and the dwarfs possessed good vitality.

The sex ratio among dwarfs is about 50:50. Thus, research workers have concluded that this type of dwarfism is not related to sex.

When dwarf calves are born to normal parents, it is known that both the sire and dam are carriers. Lush and Hazel (1954) noted that apparent exceptions to this rule were caused only by variations in the number of mates that were carriers and by the chance fluctuations which occurred in small samples. "High transmitter" bulls happened by chance to transmit a large number of dwarf genes to the small sample of calves they produced, or they were used on a cow herd having a high percentage of carriers.

Because of the low fecundity of the cow, the dwarf gene is generally introduced into a herd through a carrier bull. Used on a herd of entirely normal homozygous cows, a carrier bull would be undetected, but about one-half of his calves would be carriers. If his successor were also a carrier, about one-eighth of his calves from daughters of the first bull would be dwarfs. This would result in the second bull erroneously being considered responsible for this condition in the herd.

With the increased incidence of this type of dwarfism in many lines and herds of beef cattle, Lush and Hazel (1954) suggested the possibility that normal heterozygous carriers have been preferred in the selection of breeding stock over homozygous non-carriers. This was in agreement with earlier investigators who theorized that carriers belonged to the relatively modern type group of intermediate individuals. However, no published data have confirmed this theory.

Thus, the economic aspect of this problem has caused most recent research to be concerned with methods of control or elimination of dwarfism from beef herds. Lush and Hazel (1954) discussed the advantage and limitations of the following methods:

Clean-up by pedigree. Certain herds and families are claimed to be free of dwarfism. However, pedigrees are poor criteria because: (1) the factor may be in so few individuals of such a herd that it merely has not shown up yet, (2) errors occur in pedigrees, and (3) carrier blood lines possess many non-carriers.

Clean-up by discarding the dwarf's close relatives. This method is beneficial but loses its usefulness as the relationship becomes remote. The probability of a normal-appearing relative of a dwarf carrying the dwarf gene is as follows: parent, 100 percent; full sib, 67 percent; half sib, 50 percent; and son or daughter of a half sib, 30 to 40 percent. At present, the normal-appearing animal in the beef breeds has a probability of 15 to 25 percent of being a carrier.

Clean-up by progeny test. The probability of a carrier bull revealing his true genotype increases with the number of calves he sires out of carrier cows. It is recognized by several workers that eleven calves from known carrier cows are sufficient to establish the genetic character of a bull at the 5 percent level of probability. About sixteen calves from carrier cows would be needed to prove a bull as homozygous normal at the 1 percent level of probability.

The time involved and the inaccuracy of some of these methods have indicated their limitation as speedy means of coping with this economic problem. Thus, recent studies have been concerned with finding methods to aid in the detection of carrier animals. Lush and Hazel (1952) and Gregory et al. (1952) reported unsuccessful attempts by panels

of competent judges to distinguish between non-carriers and proven carriers by visual inspection. Dwarf calves were produced by cows and bulls differing greatly in type.

Since they found the bulging forehead to be the most consistent manifestation of dwarfism, Gregory, et al. (1951) devised a precision instrument, the profilometer, to accurately chart the head profile. By determination of the parietal-frontal juncture (PFJ) 3 cm. from the posterior origin of the profile, the mid-forehead point (MFP) at one-fourth the head length from the posterior origin, the nasal-frontal juncture (NFJ) at the point of rise of the nasal bones, and the vertical distance of each of these three points from the chart's base line, different types of basic head profiles were determined. Gregory et al. (1954) claimed that dwarfs, carriers and non-carriers could be distinguished with 90 percent or more accuracy. However, the use of this method along with progeny tests by Palmish et al. (1954) and Stonaker (1954) did not confirm the investigators' high estimate of accuracy.

A more recent method of differentiation has been initiated at Iowa State College by Dr. L. N. Hazel using X-ray pictures of the lumbar vertebrae of young calves. Using this as the basis of distinction, High (1955) reported comparisons of body measurements among dwarf, carrier and non-carrier animals. Results indicated that animals classified as carriers from X-ray pictures of the lumbar vertebrae were of more desirable beef type than non-carriers. Also, five body measurements, including weight, loin width, head length, cannon length and body

length, were used in the calculation of a discriminate function. In this function, cannon length was apparently the most discriminating of the measurements included.

According to Lush and Hazel (1954), bulginess of the forehead, X-ray pictures, blood tests, hormone activity, and measurements of the head, body, legs and tail are several plausible clues now under investigation in an effort to find accurate methods for early separation of carriers from non-carrier individuals.

CHAPTER III

EXPERIMENTAL PROCEDURE

X-Ray Equipment and Procedure

A portable X-ray machine was assembled in 1954 by Mr. H. A. Hunze¹ with the assistance of Mr. J. M. Griffith² to meet the needs of various animal roentgenology experimentation carried on by the University of Tennessee. This machine was not the product of one manufacturer, but was assembled from parts manufactured by several different firms. This machine, designed to give desired capacity while being easily transportable proved invaluable in this experiment since much handling of the equipment was necessary.

This machine had a fifty milliampere and ninety kilo-volt capacity and was easily disassembled into three main sections. The first section, the Keleket controls, was made up of a control panel consisting of an ammeter, voltmeter, filament meters, switch and an auto-transformer step adjustment. A Keleket mechanical timer calibrated in one-eighth seconds controlled the time of exposure. The control box with outlet and transformer cables weighed approximately 100 pounds and was easily handled with the aid of casters and handles. The second section consisted of a Westinghouse transformer, cathode and anode cables and attached tube head with a 4.2 millimeter focal spot tube. This 100 milliampere, eighty-five kilo-volt, high tension, step-up type transformer and its component parts weighed about 220 pounds and was the

¹H. A. Hunze, Manager of Dick X-Ray Company, Knoxville, Tennessee.

²J. M. Griffith, Assistant Animal Husbandman of the University of Tennessee.

most difficult section to handle. Excellent protection of the tube was accomplished by cloth wrapping and by placing it in a padded wooden box when not in use. A Westinghouse knockdown stand made up the third section. Consisting of a cast aluminum base with three and one-half inch casters and a five and one-half foot stainless steel upright with tube attachment and ratchet assembly, this section was easily transportable and allowed speedy adjustment of the machine during operation.

Supplemental equipment was essential. A four and one-half inch diameter cone was used for concentration of X-rays. Boxes of 10 X 12 inch Kodak Blue Brand film and eight cassettes were stored in a portable lead-lined plywood box along with a stationary wafer grid. This enabled easy transportation and protection of film which was kept close at hand during operation of the machine. Calipers graduated in one-half centimeters were used to measure loin width. Two one-eighth inch lead-lined shields, 2-1/2 X 6 feet, with 9 X 11 inch lead glass windows for viewing machine and animal gave necessary protection to operators during exposures. An extension of fifty feet of number six soft strand cable was carried for setups in places where the outlet was relatively inaccessible. However, use of the extension cable caused a reduction in voltage.

All X-ray equipment was transported with adequate room in a Chevrolet "carry-all". The equipment was easily assembled or disassembled for use or transportation within ten to fifteen minutes.

Unlike the procedure used in 1954³, each calf to be X-rayed was laid on its right side and securely strapped to a plywood board three feet wide, four feet long and three-fourths inch thick. Three 1-1/4 X 1/8 inch web belts thirty inches long were spaced on the board to permit strapping the calf around the neck, around the metacarpals of the forelegs and around the metatarsals of the hind legs (Figure 1). These belts were held firmly in place by 2 X 1/8 inch strap iron bands four inches long bolted to the platform, and provided adequate strength for restraining the calf. Twin, two inch steel rings bradded in place formed a self tightening buckle for each belt. It was found that double wrapping before buckling was necessary to secure the legs. Once the calf was secured to the platform, a heavy cloth was placed around its head and was effective in quieting the calf.

The platform was kept in relatively the same position in respect to the X-ray machine for all exposures with the calf lying with its back toward the unit. Once the calf was in place and quieted, a loaded cassette and the wafer grid were slipped under its loin in an oversized slot which enabled adjustment according to the size of the calf. This slot, the mechanical adjustments of the tube head, and slight movements of the platform made centering of the tube head of the machine on the loin and film relatively easy.

³The procedure described by J. W. High, Jr. was one of merely tying the calf, laying it on its side and X-raying the animal once it had quieted sufficiently in the hands of a helper.



Figure 1. X-ray equipment used in X-raying calves

Two or more lateral exposures were made of each calf's lumbar vertebrae using a distance of thirty inches between the X-ray tube and the film. Centering of the light beam between the third and fourth lumbar vertebrae of the calf and the center of the grid and film was always attempted in order to reduce the possibility of a distorted image. This procedure, accompanied by the use of fast film, produced excellent results with surprisingly few films ruined due to calf movement.

The machine setting for each exposure was determined by the calf's loin width. The width of the loin of calves X-rayed in this experiment ranged from nine to fifteen centimeters with a mean of approximately twelve centimeters. An attempt was made to standardize exposures by using a constant milliamperage of forty. The kilo-voltage was then set within the range of seventy to eighty-five with approximately seventy-six as the most frequent adjustment used. The two exposures were usually taken at one-fourth and three-eighths of a second at constant milliamperage and kilo-voltage for each calf. This procedure varied slightly with minor adjustments between the first and second exposures for calves when they were extremely small or particularly large.

Figure 1 shows the equipment and illustrates the method followed in taking X-rays.

Although growthiness of the calf seemed to be the controlling factor, generally the maximum age that a readable X-ray could be taken consistently with this portable machine was a little over two weeks.

The developing muscular tissue of the loin appeared to be the primary cause of hazy images. Dissection of two calves also indicated that the developing rumen on the left side and the greater density of the enlarging liver on the right, plus some other internal organ or organs, produced a masking effect of vertebral outlines. The severity of this masking effect was variable, but increased with size and age of the calf. The use of fast film, a grid and cone increased the quality of exposures over those made in 1954⁴, particularly in the case of larger calves.

The procedure used in this study was thus effective only on calves from one day to two, and possibly three, weeks of age. Efforts are being made to develop techniques which will consistently allow readable exposures to be made of calves past two weeks of age. One such technique attempted to X-ray calves standing in a small station which held the calf firmly to prevent movement and yet allowed the paunch and internal organs to fall away from the vertebrae. The results obtained by this method showed little, if any, improvement in the quality of exposures and no decrease in the masking effect.

Processing (Developing) X-ray Films

With such extensive use of X-rays in this project, a small glazed tile room was developed into a permanent darkroom. Care was taken to eliminate any source of white light around doors and windows to prevent the detrimental reflection of light from the tile. The lack of a dark-

⁴In previous work by J. W. High, Jr., slow film was used without a cone or grid, and the exposure time ranged from one to three and one-half seconds.

colored, light-absorbing finish was not important since only a fifteen-watt Kodak safe lamp was used. Corrosion-resistant, stainless steel tanks were used for all solutions. Fiber top work benches, thirty-six stainless steel film hangers, a drying rack and a mechanical alarm clock completed the equipment necessary for the efficient processing of films by hand.

The manufacturer's instructions were carefully followed in the preparation of developing and fixing solutions. Five quarts of Kodak Liquid X-ray Developer and Replenisher (Solution A) was thoroughly mixed with water (one part developer to five parts water) to fill the clean five gallon developer tank. Hardener (Solution B) was added to each freshly prepared solution. When replenisher was needed to maintain desirable quantity, one part of Solution A to two parts water was added. The same procedure was followed with Kodak Liquid X-ray Fixer and Replenisher (Solutions A and B) in the clean fixer tank, double the capacity of the developer tank. It was found that best results were obtained by mixing fresh developer after processing 300 to 350 films and new fixer solution after 600 to 700 films. Both of these solutions were kept at a constant optimum temperature by the use of a thermostatic valve on the master rinse bath tank in which the smaller solution tanks were set.

Since there was some fluctuation of water temperatures in extremely hot weather, a Kodak Time Temperature Indicator Chart was closely followed in developing films to compensate for solution temperature variations from the optimum processing temperature of 68° F.

However, the solution temperature generally allowed normal processing of four minutes in the developer, about thirty seconds in the rinse bath and a minimum of fifteen minutes in the fixer. Such processing enabled a complete batch of thirty-six films to reach the final washing, after fixing, in approximately fifty minutes at optimum temperatures. The final washing was for a minimum of one hour. The final process of drying was satisfactorily accomplished at room temperature in three to four hours by hanging the films in wall racks.

Thus, the process of developing film to obtain a well-defined image was one of careful routine procedure. No film in this experiment was unreadable due to poor darkroom procedure.

Classification of X-rays

The principles used in the classification of the X-rays were devised by Dr. L. N. Hazel of Iowa State College. During 1954, Dr. Hazel taught these principles to three members of the staff of the University of Tennessee⁵ during his classification of the first exposures. Since that time, all exposures have been classified according to this method by these three animal husbandmen.

The ventral outline of the body of the lumbar vertebrae and its vertical relationship to the ventral edges of its anterior and posterior epiphyses was used almost entirely as the basis of classi-

⁵Dr. E. J. Warwick, regional co-ordinator of Project S-10 "Beef Cattle Breeding" for the Southern Region; Dr. H. J. Smith, Associate Professor of Animal Husbandry at the University of Tennessee; and J. M. Griffith, Assistant Animal Husbandman of the University of Tennessee.

fication. The proportional size of the different parts of each vertebra and the presence of density (pressure) lines were also considered. However, the final classification was generally determined by the presence of abnormalities associated with the ventral surface of the body of the vertebrae.

Three primary classifications were used: C denoted clean or homozygous normal non-carriers; B signified heterozygous carriers; and A designated the homozygous dwarfs. If individual classifications by two or more animal husbandmen were not in agreement, the final classification for each animal was determined by the panel of three research workers reviewing each exposure. Animals with X-rays which could not be read were classified as non-readable (NR). These non-readable exposures were due primarily to the calf's being too large at the time the exposure was made or to movement of the calf during exposure. If the latter were true, a second set of exposures usually enabled classification.

When the ventral body outline of all six lumbar vertebrae produced a smooth, concave, curved line image with no irregularities, the animal was classified as C (See Figure 2). The curvature of the thirteenth rib attached to the thirteenth thoracic vertebra and projection of the hip bone often hindered the determination of the true ventral body outline of the first and sixth lumbar vertebrae, respectively. However, this obstructive effect, chiefly in the pelvic region, generally gave trouble in classification only in the case of older calves. The outline of the four unobstructed lumbar vertebrae

the second through the fifth, was usually sufficient for classification.

Animals classified as B type, or carriers, exhibited a variety of vertebral shapes. In general, the ventral body outlines showed small irregular protrusions or teat-like projections. In addition to these projections, they were more straight-lined than the C type and did not exhibit the normally smooth contour. Density lines, probably indicating some inward pressure, were shown by some B type vertebrae, especially in the more extreme cases. Due to the wide variation with which these vertebral carrier characteristics were found, the B type classification was further divided into seven sub-classes, B₂ through B₈, depending on the number of abnormally shaped vertebrae and the number and size of projections. Those animals whose vertebrae approached those of C type animals were classified B₂ (See Figure 3). However, the distinction between these two classes was not easily defined, and many calves classified as B₂'s may represent non-carriers (C type). Breeding tests will be necessary to check the accuracy of classification. Exposures not exhibiting a smooth curved ventral body outline and showing slight indication of irregularities were placed in the B₂ classification. B₃ was the first classification exhibiting vertebrae with a decidedly irregular and shallower concavity of the ventral body outline and definite projections on at least one of the lumbar vertebrae (See Figure 4). The carrier classification number was increased as the concaved appearance of the ventral body outline tended to straighten and the number of vertebrae with definite pro-

jections increased. B₄ and B₅ animals had rather straight ventral body outlines of the posterior lumbar vertebrae with the severity of the irregularities and projections on all six vertebrae differentiating these two classes (See Figures 5 and 6). B₆ animals were the first to possess rather large projections which protruded below the plane of the rounded anterior and posterior body ends of individual vertebra (See Figure 7). The vertebrae of animals in the B₇ classification were relatively uniform with all showing ventrodorsal thickness of the central body regions and pronounced double projections, particularly on the posterior vertebrae (See Figure 8). Lumbar vertebrae of animals in the last carrier classification, B₈, exhibited the most extreme abnormalities of all the B types. The large twin projections extended down well below the normal ventral body outline, producing a convex appearance (See Figure 9). The density lines which became more intense with the progression of carrier classifications were evident in B₈ animals.

The dwarf, or A, animals were rather easily distinguished by X-ray classification from C or B types. The body of a dwarf vertebra was relatively short, and the ventral body outline slanted inward from the epiphyseal junctures toward large twin protrusions, a complete reversal from the normal vertebra (See Figure 10). The anterior and posterior epiphyses of the lumbar vertebrae of dwarfs were characteristically wider and longer than those of C and B types. In all dwarf calves thus far X-rayed, the epiphyses of the lumbar vertebrae were as long as the body of the vertebrae. In a few cases

this is the main point of differentiation between extreme carrier types (B and B) and dwarfs. Thus, a clean break was found between most carrier animals and dwarfs.



Figure 2. C type vertebrae



Figure 3. B2 type vertebrae



Figure 4. B_3 type vertebrae

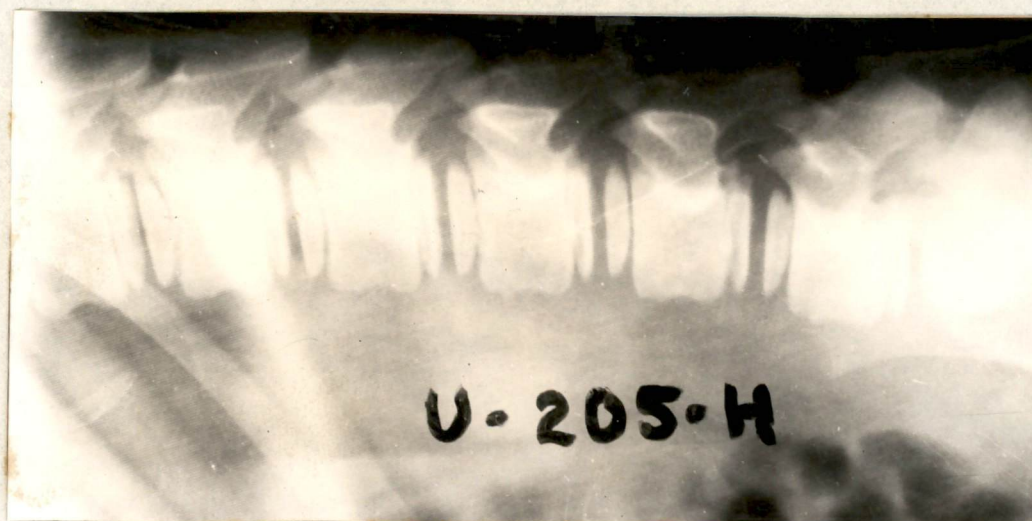


Figure 5. B_4 type vertebrae



Figure 6. B₅ type vertebrae



Figure 7. B₆ type vertebrae

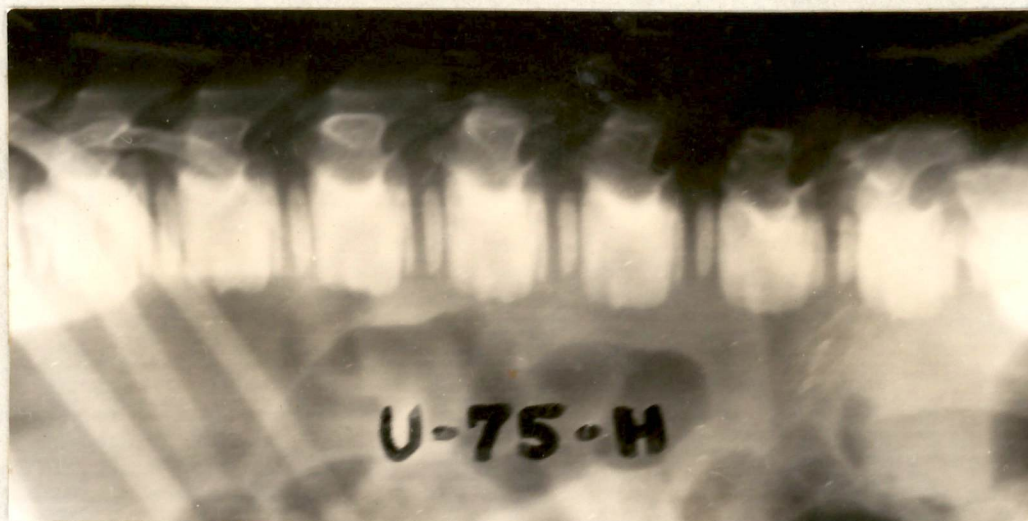


Figure 8. B₇ type vertebrae



Figure 9. B₈ type vertebrae



Figure 10. A type vertebrae

CHAPTER IV

RESULTS AND DISCUSSION

The 1955 spring calf crop, consisting of the progeny of twenty-six purebred beef bulls (twenty-three Herefords and three Angus), was used to investigate the value of X-ray Techniques in the detection of animals heterozygous for recessive bovine dwarfism. This large number of sires permitted the study of the progeny of several proven carrier bulls (those that had previously sired dwarfs), a number of suspected carrier bulls and several bulls which were thought to be clean.

All sires and dams and the subsequent offspring were the property of six different stations under the supervision of the University of Tennessee Agricultural Experiment Station. One co-operator herd under control of the University of Tennessee was included, also. The genotypes of the cows with respect to dwarfism were unknown with the exception of the few dams of previous dwarfs. However, in the 1954 breeding programs at these various locations, with the exception of Greeneville and Crossville, the cow herds were divided into comparable sire breeding groups on the basis of type and conformation, weight, age and breeding of the cows. Thus, the sire breeding groups at most stations were presumed to be comparable genetically with a random distribution of carrier cows among sire groups at each station. History of dwarfism and pedigree information indicate considerable differences in the ratios of clean to carrier cows in the herds of different stations.

The lumbar regions of 443 calves (both male and female) were

X-rayed as described in the experimental procedure. These calves included all the living progeny of each bull on test and an occasional dead calf where it was possible to X-ray before disposal. A minimum of two lateral lumbar exposures of each calf was taken, and this enabled genotypic classification of essentially all calves according to Hazel's method of distinguishing between carrier and non-carrier animals. When both original exposures were non-readable, it was sometimes possible to take a second set before the calf became too large. This eliminated non-readable classifications in some cases, and a total of only fourteen calves remained unclassified.

X-ray classification of the progenies of the bulls used in this study is given in Appendix Table IV. A summary of the ratio of C, B and A types among the progeny of each bull is given in Table I. It was necessary to assume in this study that the technique of classification was accurate in differentiating the three types of calves (homozygous normals, heterozygous normal carriers and dwarfs). However, in some cases there was uncertainty about the accuracy of the classification of some C (non-carrier) and some B₂ (carrier) animals. Thus, these questionable classifications were listed as C? and B₂?, respectively, indicating the most probable classification but showing that vertebral characteristics were not distinct enough to positively (without reservation) place a calf in this classification. There was not a clear-cut break, therefore, on the basis of the limited studies to date to definitely differentiate the C and the least extreme B type (B₂). In the analysis, however, the questionable calves were tabu-

TABLE I

RATIOS OF X-RAY TYPES AMONG THE PROGENIES OF BULLS OF CARRIER AND UNKNOWN GENOTYPES

Station	Breed	Exp. No. of Bull	Sire Genotype	Non-Carriers			Carriers										Dwarf A	NR ^a	Remarks on 1955 Progeny		
				Total Progeny X-Ray'd	C	C?	Total C's	B ₂	B ₂ ?	B ₂ 's	Total	B ₃	B ₄	B ₅	B ₆	B ₇				B ₈	Total B's
Alcoa	Hereford	1	Carrier ^b	19	3	2	5	3	1	4	4	1	5	1	1	-	-	12	1	2 dwarfs, 1 born dead, no X-ray	
		2	Carrier ^b	18	2	3	5	3	1	4	4	5	-	1	-	-	-	10	2		
		3	Carrier ^b	17	2	1	3	2	3	5	5	3	1	1	2	-	-	12	1		
		4	Carrier ^b	22	1	2	3	5	1	6	6	8	-	3	-	-	-	-	17	1	Twin male calves, B ₂ and B ₄
		5	Carrier ^b	15	4	-	4	6	-	6	6	3	2	-	-	-	-	-	11	-	
		6	Unknown	18	6	-	6	3	2	5	5	4	2	-	1	-	-	-	12	-	
		7	Unknown	16	-	2	2	8	2	10	10	2	-	-	-	1	-	-	13	1	
		8	Unknown	20	5	2	7	8	2	10	10	2	1	-	-	-	-	-	13	-	
		9	Unknown	19	8	4	12	4	1	5	5	1	1	-	-	-	-	-	7	-	
		164	31	16	47	42	13	55	29	12	6	5	-	-	-	-	107	6			
Blount	Hereford	10	Carrier ^b	10	1	-	1	1	-	1	1	-	4	-	-	1	-	7	-		
		11	Unknown	8	1	-	1	1	2	3	2	-	-	1	-	-	1	7	-		
				18	2	-	2	2	4	4	3	4	1	-	1	1	14	-			
Spring Hill (Columbia)	Hereford	12	Unknown	18	2	1	3	4	3	7	7	4	2	1	-	-	-	14	1	Twin female calves, B ₂ and B ₄	
		13	Unknown	17	8	3	11	3	1	4	4	-	-	-	-	-	-	4	2		
				35	10	4	14	7	4	11	11	4	2	1	-	-	18	3			
Greeneville	Hereford	14	Carrier ^b	17	4	3	7	6	2	8	8	1	-	-	-	-	-	9	1		
		15	Carrier	18	1	1	2	8	4	12	12	3	-	-	-	-	-	15	-		
				35	5	4	9	14	6	20	20	4	-	-	-	-	24	1			
Oak Ridge	Hereford	16	Carrier	12	4	2	6	1	-	1	1	2	1	-	-	-	-	4	-	3 dwarfs, 1 died, no X-ray	
		17	Unknown	14	4	3	7	3	2	5	5	1	-	-	-	-	-	6	1		
		18	Unknown	20	11	5	16	1	2	3	3	1	-	-	-	-	-	4	-		
		19	Unknown	22	6	2	8	2	5	7	7	4	2	-	-	1	-	14	-		
		20	Unknown	20	13	3	16	3	1	4	4	-	-	-	-	-	-	4	-		
		21	Unknown	14	4	1	5	5	-	5	5	3	-	-	-	-	-	8	1		
				102	42	16	58	15	10	25	11	3	-	-	-	1	-	40	2		
Springfield	Hereford	22	Unknown	5	3	1	4	-	1	1	1	-	-	-	-	-	1	-			
		23	Unknown	13	6	4	10	1	2	3	3	-	-	-	-	-	-	3	-		
				18	9	5	14	1	3	4	4	-	-	-	-	-	4	-			
Blount	Angus	24	Unknown	18	2	4	6	5	3	8	8	4	-	-	-	-	12	-			
Crossville	Angus	25	Unknown	28	12	5	17	7	-	7	7	4	-	-	-	-	11	-	Twins- male and female, both C		
		26	Unknown	25	8	7	15	4	3	7	7	1	-	-	-	-	-	8		2	
				53	20	12	32	11	3	14	14	5	-	-	-	-	19	2			
				443	121	61	182	97	44	141	141	60	21	8	5	2	1	238	9	14	

^aNR = Non-readable X-rays.^bDwarf sired in previous years.

lated in the total for their respective classifications.

The results of only a limited number of breeding or progeny tests are available to confirm or contradict the accuracy of classification of calves into C (clean) and B (carrier) types on the basis of abnormalities of the lumbar vertebrae. There is no problem involved in the differentiation between C and B types (normal phenotypically) and the A type (dwarf) since the dwarf calf is easily recognized at birth or shortly thereafter by one who has had only limited experience with the defect. A considerable number of dwarf calves were X-rayed in this study and their X-rays were rather easily distinguished from the most extreme B type (B_g) X-rays, indicating a definite break between the B type and A type X-ray classifications. Further progeny tests are needed to test the accuracy of the classification into C or B types by this method. These tests should provide the information required to define the characteristics which will give a clear-cut and accurate separation between the C type and B₂ type carrier. It is probable that some of the calves classified as B₂ in this study may actually be C type animals.

Nine (Herefords) of the twenty-six bulls are known carriers (See Table I), having sired dwarfs this year or previously. The genotypes of the remainder of the bulls were unknown. However, it is thought that Hereford bull 22 may be clean since he has sired four calf crops and produced no dwarfs. This bull was mated to eight of his daughters in 1954 and of the five calves resulting from these matings all were normal. This bull and a son (Hereford bull 23) sired eighteen calves in 1955, and fourteen of them X-rayed C type. The results of C:B

types among the progenies of these two bulls were 4C:1B and 10C:3B for bulls number 22 and 23, respectively. All of the B types in the calves by these bulls were classified as B₂. No extreme carrier types were found in this herd.

The genotypes of the Angus bulls included in the study were unknown, although pedigree information and the fact that they have produced several calf crops would lead to the assumption that they might be clean. The large number of B type calves in the progenies of these bulls does not appear to substantiate this hypothesis, however. Since no dwarfs have ever been produced in these herds and there is little history of dwarfism in these lines of breeding it is likely that the cow herds are relatively free of the dwarf gene.

In the statistical analysis, it was assumed that each sire was a carrier (Dd), whether his genotype was proven or not. Although it is known that several cows in some groups were carriers, it was also assumed for statistical analysis that all cow herds were clean (DD). Thus, on the basis of these assumptions and on the theory that a monofactorial recessive gene is the mode of inheritance for the "snorter" type dwarfism, one could expect such matings to produce, on the average, a 50:50 ratio of carrier and non-carrier calves.

This hypothesis was made because of the limited information available for the assumption of a definite percentage or number of carrier cows in the sire breeding groups at each station. In groups of cows in which dwarf calves were produced, an assumption of a minimum of four carrier cows for each dwarf calf produced might be made.

This would indicate that approximately 20 to 25 percent of the cows in the herds at some stations were carriers of the dwarf gene. The possibility exists that this was even higher in some groups. This would, of course, be an important factor in the deviation of actual observed ratios from the expected 50:50 ratios (as set up by the hypothesis) in the case of the progenies of carrier bulls. It would also be responsible for the B type calves in the progenies of clean bulls. In view of these possibilities, the ratios of calves from matings of carrier bulls to cow herds with a relatively high percentage of carrier cows could be expected, in some cases, to depart significantly from expected ratios. On the same basis, clean bulls mated to groups of cows with a large number of carrier cows could be expected to have a number of B type calves in their progenies.

On the basis of these assumptions, it was thought that the similarity to and/or deviation of the observed ratios of sire progenies from expected ratios might be of some value in the identification of carrier or non-carrier bulls. Table II gives the Chi-squares and the probabilities for the deviation of the observed ratios from the expected ratios.

The progenies of nine Hereford bulls were X-rayed at Alcoa. Five of these bulls (numbers 1, 2, 3, 4 and 5) were known carrier bulls, having sired dwarf calves in previous years. Four of these five carrier bulls sired one dwarf calf each in 1955. This would indicate that the minimum number of carrier cows for each sire breeding group was at least four and possibly higher. With a range of fifteen to twenty-two calves

Probability

0.05 P 0.10
 0.10 P 0.20
 0.02 P 0.05
 0.001 P 0.01
 0.05 P 0.10
 0.10 P 0.20
 0.001 P 0.01
 0.10 P 0.20
 0.20 P 0.30

0.02 P 0.05
 0.02 P 0.05

0.001 P 0.01
 0.05 P 0.10

0.50 P 0.70
 0.001 P 0.01

0.50 P 0.70
 0.70 P 0.80
 0.001 P 0.01
 0.20 P 0.30
 0.001 P 0.01
 0.30 P 0.50

0.10 P 0.20
 0.05 P 0.10

0.10 P 0.20

0.20 P 0.30
 0.10 P 0.20

the cows were clean.

in the sire progenies, approximately 20 to 25 percent of the cows in the groups of cows mated to carrier bulls would be carriers. The genotypes of four of the bulls were unknown. Since all groups of cows at Alcoa were considered to be of similar genotype, the groups of cows mated to the bulls of unknown genotype should have included about the same number of carrier cows as those groups mated to carrier bulls. Three of the bulls at this station (3, 4 and 7) had progenies in which observed ratios of C to B types departed significantly from the expected 50:50 ratios of C:B types. Two of these (3 and 4) were known carriers and the genotype of one (bull 7) was unknown. However, in all of the progenies except one (progeny of bull 9) the number of B type calves was greater than the C type. This would be expected in the case of carrier bulls mated to groups of cows in which 20 to 25 percent or more of the cows were carriers. The results appear to incriminate the four bulls of unknown genotypes as carriers of the dwarf gene. If they are carriers and with as high a percentage of carrier cows as indicated by the number of dwarfs sired by carrier bulls on similar groups of cows, it would seem that at least one or more of these bulls of unknown genotypes should have sired dwarf calves.

Progenies of two Hereford bulls (10 and 11) X-rayed at Blount Farm, Knoxville, had identical ratios of C:B types of 1C:7B. Bull 10 is a known carrier, and the genotype of Bull 11 is unknown; however, the significant departure from the expected ratio would tend to incriminate Bull 11 as a carrier. The preponderance of B type calves in the ratios of these two bulls may be due to the presence of a number of

carrier cows in this herd since a few have produced dwarf calves and pedigree information would indicate that others may be carriers of the dwarf gene.

At Spring Hill (Columbia) Station, the ratios of C:B types in the progenies of Hereford bulls 12, and 13 were 3C:14B and 11C:4B, respectively. The genotype of these bulls was unknown, but these results suggest that bull 12 may be a carrier and bull 13 non-carrier. Little information is available for speculation as to number of carrier cows in this herd; however, the information available would indicate that this herd is relatively clean.

Both of the Hereford bulls included in the study at the Greenville station are known carriers. Bull 14 was mated to a group of cows which was believed to be largely clean. The ratio of C:B types among the progeny of this bull was 7C:9B. Bull 15 was mated to a group of twenty-nine cows, twelve of which were his own half-sisters. This bull and his half-sisters were sired by a known carrier bull. The ratio of C:B types among the progeny of this bull was 2C:15B which represented a highly significant departure from a 50:50 ratio. The high proportion of B type calves by this bull may be partially explained by the high percentage of carrier cows in the group bred to this bull.

The progenies of six Hereford bulls were X-rayed at Oak Ridge. Bull 16, a known carrier, was mated to thirteen grade Hereford cows, all of which had been sired by two known carrier bulls. Eight of the cows were half-sisters of the bull. The ratio of C:B types among the progeny of this bull was 6C:4B. Three dwarf calves were also produced

by this bull. The genotypes of the other five bulls were unknown, and there was little basis for estimating the number of carrier cows in this herd although it is presumed the herd is relatively clean. Two of these bulls (numbers 18 and 20) had the same ratios of C:B types of 16C:4B. These were highly significant departures from expected 50:50 ratios. This would seem to indicate that these bulls are non-carriers of the dwarf gene since the B types in these ratios could well be due to the presence of carrier cows. Bulls 17, 19 and 21 had progenies with ratios of 7C:6B, 8C:14B and 5C:8B, respectively. These ratios would tend to incriminate these bulls as carriers if the cow herd is relatively free of the dwarf gene.

The ratios of presumed clean to carrier in the progenies of the Angus bulls included in this study were 6C:12B, 17C:11B and 15C:8B for bulls 24, 25 and 26, respectively. None of these ratios was a significant departure from a 50:50 ratio and would tend to incriminate these bulls as carriers. There is no previous history of dwarfism in the Angus herds at Blount or Crossville, and indications are that the herds are relatively free of the dwarf gene. There was also some inbreeding in the calves at Crossville (0 to 20 percent) and if the bulls were actually carriers, this should have increased the probability of obtaining a dwarf from one of the bulls at this station.

Observations and study of the vertebrae of Hereford and Angus calves indicate that there are possibly real differences in type of vertebrae between breeds. Since most studies have been made with Hereford cattle, the results of these studies may not be entirely applicable to the vertebrae of Angus cattle. Until these differences, if any, are

are clarified, these ratios in the Angus progenies may not be accurate.

In all probability, some of the calves classified as B₂ (carrier) from the X-ray exposures of the lumbar vertebrae may be actually C type (non-carrier). However, until definite evidence from breeding tests is available to define the break between C and B₂ types, it was thought best to place questionable cases into the B₂ type. When these data become available, the ratios of the various types of calves by these bulls will likely be changed somewhat and will provide more accurate information for evaluating the genotype of the bulls with respect to the dwarfism gene.

Results of these X-ray studies of the lumbar vertebrae of young calves in beef cattle show that the lumbar vertebrae of the "snorter" dwarf (A type) are distinct morphologically from those of phenotypically normal calves, both presumed clean and presumed carrier. X-ray pictures of the lumbar vertebrae of calves give a distinct separation between dwarf and normal calves. The point of differentiation between homozygous normal (C type) and heterozygous normal (B type), is not as clearly defined. This problem is primarily associated with characteristics which will differentiate clearly between C type and the least extreme B type (B₂). The degree of vertebral abnormalities is sufficiently distinct in B₃ to B₈ type carriers to separate these types from the C type.

The ratio of the X-ray C and B types among the progeny of a bull would seem to offer some promise as a means of evaluating a sire as a clean or carrier animal provided that the number of calves is fairly

large and that some information is available on the probable number of carrier cows in the herd.

Further refinement and the ultimate value of the X-ray technique in the identification of carrier animals will depend upon progeny tests to evaluate the accuracy of the classification of calves into C or B types by this method.

A progressive X-ray study was made of the vertebrae of fourteen calves, in which exposures were taken at intervals of approximately one week up to about eight weeks of age. One of the purposes of this study was to determine if structural changes occur in the maturing vertebrae and the subsequent effect upon the genotype classification of the calves. This study was made also to determine the maximum size and age at which readable X-ray exposures of calf vertebrae could be made with the machine used. The results of this study are given in Table III. Only slight changes were noted in some cases of carrier types, generally toward normalcy. Part of these changes in classification were probably caused by poor quality exposures associated with increased age and thickness which resulted in masking effects in the X-ray pictures. Some of the changes, however, were probably real and indicate that classification may change slightly with age. The maximum limits for X-raying were found to be two to three weeks of age and a loin width of thirteen to fourteen centimeters. Thus, the study indicates that calves should be X-rayed as soon after birth as possible (within two to three weeks) in order to obtain X-ray exposures of maximum quality for classification.

TABLE III

X-RAY CLASSIFICATION OF CALVES AT VARIOUS AGES

Tattoo	Breed	Exp. No. of Bull	Station	Age in Days	X-Ray Classi- fication	Width of Loin in Cm.
U15	Angus	24	Blount	6	B ₂	11.0
				11	B ₂	11.5
				27	B ₂	12.0
				34	B ₂	13.0
				41	B ₂	13.0
				62	B ₂	14.0
U25	Angus	24	Blount	7	C?	9.5
				23	C?	11.0
				30	C?	13.0
				37	C?	13.0
				58	C?	14.0
U35	Angus	24	Blount	22	B ₃	13.0
				29	B ₃	13.0
				36	NR	13.5
				57	NR	15.5
U45	Angus	24	Blount	2	B ₂ ?	10.0
				18	B ₂	11.5
				25	C	12.0
				32	C	13.0
U55	Angus	24	Blount	15	C?	11.5
				22	C	12.0
				29	B ₂ ?	13.0
U65	Angus	24	Blount	11	B ₂ ?	11.5
				18	B ₂ ?	13.0
				25	NR	15.0
U75	Angus	24	Blount	8	B ₂	11.5
				15	B ₂ ?	11.5
				22	C	12.0

TABLE III (Continued)

X-RAY CLASSIFICATION OF CALVES AT VARIOUS AGES

Tattoo	Breed	Exp. No. of Bull	Station	Age in Days	X-Ray Classi- fication	Width of Loin in Cm.
U85	Angus	24	Blount	8	B ₂	10.5
				15	B ₂	12.0
				22	NR	14.0
				43	NR	16.0
U95	Angus	24	Blount	6	B ₃	11.0
				13	B ₂	12.5
				20	B ₂	13.0
				41	NR	14.0
U105	Angus	24	Blount	6	C?	11.0
				13	C?	12.0
				20	NR	13.5
U115	Angus	24	Blount	5	B ₂	10.5
				12	B ₂	12.0
				19	B ₂	13.0
				40	NR	15.0
U15	Hereford	10	Blount	3	B ₄	9.5
				19	B ₃	12.0
				26	B ₃	12.0
				33	B ₂	13.5
				54	NR	14.0
U25	Hereford	10	Blount	12	B ₃	12.0
				19	B ₃	12.0
				26	B ₃	13.5
U35	Hereford	10	Blount	4	B ₄	12.0
				11	B ₄	12.0
				32	B ₃	14.0

CHAPTER V

SUMMARY

The lumbar regions of 443 calves were X-rayed in order to study the value of X-ray techniques in distinguishing between animals homozygous for the normal allele of the "snorter" dwarf gene and those heterozygous for the recessive dwarf gene. A minimum of two exposures was taken of each calf. These calves were the 1955 progeny of Hereford and Angus purebred bulls mated to purebred and grade Hereford and Angus cows of their respective breeds. All parent individuals were under control of the University of Tennessee, constituting herds at six different agricultural experiment stations and one co-operator herd. Bulls that were proven carriers, several suspected carriers and some that were thought to be clean were represented among the sires included in the study.

Using the method advanced by Dr. L. N. Hazel of Iowa State College, the calves were classified as clean (C type), carrier (B type) or dwarf (A type) according to the characteristics of their lumbar vertebrae as revealed by X-ray image. After individual classification of the calves, the ratio of non-carrier to carrier individuals for each bull was calculated. Nine bulls sired dwarfs in 1955, or previously, and were regarded as proven carriers. These proven carrier bulls generally tended to sire a predominance of carrier (B type) calves according to the X-ray classification. This was probably due to a number of carrier cows in the herds bred to these bulls, as a carrier bull mated to clean cows should produce approximately a 50:50 ratio

of clean to carrier animals.

The observed ratios of C:B types among the progenies of seventeen bulls of unknown genotypes were variable. The progenies of twelve of these bulls had ratios of C:B types which did not depart significantly from expected ratios. In some cases, the ratios had a preponderance of C or B types and these approached significance. This variation in ratios would be expected in cases where carrier bulls were mated to cow herds in which there was a high percentage of carrier cows, or where clean bulls were bred to cow herds with a number of carrier cows. Two bulls had ratios which deviated significantly from expected ratios with a large proportion of C type calves, while three bulls had ratios which deviated significantly from expected ratios with a predominance of B type calves. This indicates that these bulls may be non-carriers or carriers of the gene for dwarfism, respectively.

Progressive X-ray studies of the vertebrae of fourteen calves in which exposures were taken at approximately weekly intervals up to eight weeks of age indicated that two, and possibly three, weeks of age and a loin width of about thirteen centimeters were the upper limits at which readable X-rays could be taken with a machine of the capacity used in this study. These limits could possibly be increased with a machine of greater capacity.

Results of these X-ray studies of the lumbar vertebrae of young calves in beef cattle show that the lumbar vertebrae of the "snorter" dwarf (A type) are distinct morphologically from those of phenotypically normal calves, both presumed clean and presumed carrier. X-ray pictures

of the lumbar vertebrae of calves give a distinct separation between dwarf and normal calves. The point of differentiation between homozygous normal (C type) and heterozygous normal (B type), is not as clearly defined. This problem is primarily associated with characteristics which will differentiate clearly between the C type and the least extreme B type (B₂). The degree of vertebral abnormalities is sufficiently distinct in B₃ to B₈ type carriers to separate these types from the C types.

The ratio of the X-ray C and B types among the progeny of a bull would seem to offer some promise as a means of evaluating a sire as a clean or carrier animal provided that the number of calves is fairly large and that some information is available on the probable number of carrier cows in the herd.

Further refinement and the ultimate value of the X-ray technique in the identification of carrier animals will depend upon progeny tests to evaluate the accuracy of the classification of calves into C or B types by this method.



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APPENDIX

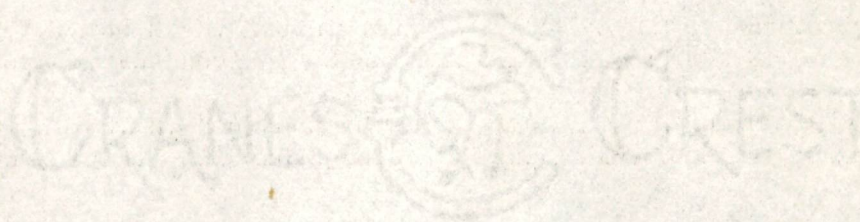


TABLE IV

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 1
ALCOA - HERD BA

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A612	2/2	65	66	M	2/10	8	C
A616	2/4	55	182	F	2/10	6	B ₄
A625	2/5	63	39	M	2/10	5	B ₂
A652	2/20	68	57	M	3/3	11	C
A658	2/21	63	179	F	3/3	10	C
A667	3/1	67	52	F	3/3	2	B ₄
A669	3/1	35	A305	M	3/3	2	B ₄
A673	3/3	66	61	M	3/22	19	B ₅
A679	3/10	55	221	F	3/22	12	B ₂
A684	3/14	63	220	M	3/22	8	B ₂
A693	3/31	60	213	M	4/7	7	B ₆
A695	4/4	47	A325	F	4/7	3	B ₄
A703	4/9	78	35	F	4/19	10	B ₂ ?
A707	4/12	60	208	F	4/19	7	C?
A727	7/1	60	A307	M	7/1	0	NR
-	1/28	60	188	M	-	-	A ^a
G559	2/2	78	G139	M	2/10	8	B ₃
G567	2/7	64	G325	F	2/10	3	B ₄
G613	3/4	62	G371	M	3/22	18	C?
G628	4/10	59	G277	M	4/19	9	A

^aThis calf was born dead and was not X-rayed. It was classified as A from dwarf characteristics.

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 2
ALCOA - HERD CA

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A609	2/1	64	222	F	2/10	9	B ₃
A610	2/1	53	A346	M	2/10	9	B ₂
A615	2/4	55	180	F	2/10	6	B ₂
A619	2/4	63	14	M	2/10	6	B ₃
A627	2/7	77	192	M	2/10	3	B ₂
A635	2/10	55	11	F	2/10	0	B ₃
A639	2/14	73	190	F	3/3	17	NR
A642	2/15	65	A373	M	3/3	16	C?
A665	2/27	70	51	M	3/3	4	NR
A694	4/3	66	34	M	4/7	4	C?
A706	4/12	77	223	M	4/19	7	B ₃
A710	4/19	65	A303	F	5/3	14	C?
A724	5/23	80	202	F	6/2	10	B ₂ ?
A725	6/1	64	198	F	6/2	1	A
G553	1/27	45	G324	F	2/10	14	C
G563	2/4	47	G359	F	2/10	6	C
G569	2/7	94	G270	M	2/10	3	B ₃
G573	2/10	68	G302	M	2/10	0	B ₅

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 3
ALCOA - HERD FA

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A624	2/6	61	A329	F	2/10	4	B ₆
A634	2/10	60	24	F	2/10	0	C
A647	2/17	60	48	M	3/3	14	B ₂ ?
A649	2/17	55	71	F	3/3	14	C
A654	2/20	63	189	M	3/3	11	A
A655	2/21	70	186	M	3/3	10	B ₃
A656	2/21	63	64	F	3/3	10	B ₄
A661	2/25	66	77	F	3/3	6	B ₂ ?
A681	3/11	67	A366	M	3/22	11	B ₅
A687	3/22	68	200	F	4/7	16	B ₃
A688	3/22	59	A315	F	4/7	16	B ₂
A689	3/23	68	178	M	4/7	15	B ₂
A696	4/4	61	203	F	4/7	3	B ₆
A723	5/23	65	196	F	6/2	10	B ₃
G581	2/12	76	G328	M	3/3	19	C?
G614	3/6	63	G278	F	3/22	16	B ₂ ?
G631	4/29	58	G353	M	5/3	4	NR

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 4
ALCOA - HERDS GA AND RB

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A606	1/30	55	9	M	2/14	15	B ₂
A620	2/6	70	72	M	2/14	8	C?
A621	2/6	69	62	F	2/14	8	B ₃
A622	2/6	46	3	F	3/3	25	C?
A637	2/8	70	177	M	2/14	6	B ₅
A646	2/17	65	181	M	3/3	14	B ₂
A664	2/28	70	073	M	3/8	8	B ₂
A670	3/2	60	-82	F	3/8	6	B ₂
A682	3/13	64	-71	M	3/22	9	B ₃
A692	3/20	60	214	M	4/7	18	A
A699	4/3	70	A317	M	4/7	4	B ₃
A700	4/4	48	A328	M	4/7	3	B ₂
A708	4/18	55	194	F	4/19	1	B ₃
A709	4/8	65	205	M	4/19	11	B ₂ ?
A715	4/28	64	715	M	5/3	5	B ₃
A717	4/25	72	197	M	5/3	8	B ₅
A719	5/6	66	247	M	5/17	11	C
A729	6/30	60	225	F	7/5	5	NR
G556	1/25	60	G365	F	2/14	20	B ₃
G560	2/3	62	G258	M	2/10	7	B ₃
G570	2/7	68	G141	F	2/10	3	B ₃
G574	2/10	56	G320	M	2/14	4	B ₅

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 5
ALCOA - HERD OA

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A617	2/4	44	794	M	2/10	6	B ₄
A618	2/4	44	794	M	2/10	6	B ₂
A630	2/9	50	762	F	2/10	1	B ₄
A632	2/9	55	266	M	2/10	1	B ₂
A662	2/27	49	736	F	3/8	9	C
G561	2/4	56	G244	M	2/10	6	C
G568	2/7	57	G264	F	2/10	3	B ₃
G582	2/14	68	G156	F	3/8	22	C
G584	2/12	67	G103	M	3/8	24	B ₂
G590	2/18	61	G31	F	3/8	18	B ₂
G591	2/19	63	G269	F	3/8	17	C
G592	2/21	60	G159	M	3/8	15	B ₂
G601	2/28	43	G250	F	3/8	8	B ₃
G604	3/2	64	G271	M	3/8	6	B ₃
G610	3/3	71	G256	M	3/8	5	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 6
ALCOA - HERD AA

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A600	1/25	33	209	F	2/10	16	B ₃
A602	1/28	57	A341	F	2/10	13	B ₂
A605	1/31	39	A344	M	2/10	10	C
A614	2/3	67	31	M	2/10	7	B ₂ ?
A629	2/8	55	79	M	2/10	2	B ₆
A631	2/9	73	185	F	2/10	1	B ₃
A638	2/14	54	6	F	3/3	17	B ₃
A651	2/20	63	45	F	3/3	11	C
A678	3/10	58	A314	M	3/22	12	C
A683	3/14	65	47	M	3/22	8	C
A685	3/16	65	16	M	3/22	6	B ₄
A690	3/26	75	176	F	4/7	12	B ₂
A691	3/25	68	199	M	4/7	13	C
A697	4/4	59	210	F	4/7	3	B ₂ ?
A722	5/20	74	224	F	6/2	12	C
G552	1/24	60	G321	F	2/10	17	B ₄
G558	2/2	63	G360	F	2/10	8	B ₃
G600	2/27	63	G283	M	3/3	4	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 7
ALCOA - HERD DA

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A604	1/30	62	A340	F	2/14	15	B ₂
A608	2/1	78	32	F	2/14	13	B ₃
A623	2/5	80	183	M	2/14	9	C?
A636	2/10	58	A367	M	2/14	4	B ₂
A645	2/16	56	21	M	3/3	15	B ₂ ?
A653	2/20	56	25	M	3/3	11	B ₂
A666	2/26	68	60	M	3/3	5	B ₂
A668	3/1	60	207	F	3/3	2	B ₃
A674	3/4	72	219	M	3/22	18	B ₂ ?
A705	4/11	80	215	M	4/19	8	NR
A720	5/5	85	68	M	5/17	12	B ₂
A728	7/1	70	206	F	7/5	4	B ₆
G554	1/29	67	G367	F	2/14	16	C?
G555	1/30	72	G279	M	2/14	15	B ₂
G571	2/8	69	G267	F	2/10	2	B ₂
G623	3/29	74	G319	M	4/7	9	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 8
ALCOA - HERD RA

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A640	2/15	59	84	F	3/8	21	C
A650	2/19	67	260	F	3/8	17	B ₂
A657	2/21	63	275	M	3/8	15	B ₂
A659	2/24	58	7	M	3/8	12	B ₂
A671	3/2	65	793	M	3/22	20	C
A677	3/8	62	78	F	3/22	14	B ₂
A680	3/10	58	235	F	3/22	12	B ₂ ?
A686	3/19	80	761	M	4/12	24	B ₄
A701	4/5	59	777	F	4/12	7	B ₂
A702	4/5	72	218	M	4/12	7	C?
A704	4/11	71	-84	F	4/19	8	C?
A711	4/21	80	745	F	5/3	12	C
A713	4/18	70	244	M	5/3	15	C
A714	4/26	75	226	M	5/3	7	B ₃
G562	2/4	53	G7	F	2/10	6	B ₂
G572	2/10	64	G25	M	2/10	0	B ₂
G583	2/14	57	G22	F	3/8	22	B ₂ ?
G599	2/25	67	G1	M	3/8	11	C
G612	3/4	55	G13	F	3/22	18	B ₃
G618	3/13	59	G15	M	3/22	9	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 9
ALCOA - HERD RC

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
A601	1/28	55	796	M	2/10	13	C
A603	1/30	64	-77	M	2/10	11	B ₂
A607	2/1	63	710	F	2/10	9	B ₃
A611	2/2	60	756	F	2/10	8	B ₂
A613	2/3	62	768	M	2/10	7	C
A626	2/7	65	718	F	2/10	3	C?
A628	2/8	54	799	M	2/10	2	B ₂ ?
A633	2/9	50	7104	M	2/10	1	C
A641	2/15	48	789	M	3/8	21	C?
A643	2/16	54	730	M	3/8	20	C
A644	2/16	59	713	M	3/8	20	B ₂
A648	2/18	55	791	F	3/8	18	C
A660	2/24	54	22	M	3/8	12	B ₂
A675	3/5	57	766	M	3/22	17	C
A676	3/6	58	750	M	3/8	2	C?
A1699	4/5	61	63	M	4/7	2	C
A712	4/24	70	722	F	5/3	9	C?
A716	4/30	63	-60	M	5/3	3	C
A718	5/2	76	788	M	5/3	1	B ₄

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 10
BLOUNT

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
U15	1/31	54	BH-72	F	2/3	3	B ₄
U25	2/7	65	394	F	2/19	12	B ₃
U35	2/22	77	959	M	2/26	4	B ₄
U45	3/1	62	698	F	3/5	4	B ₄
U55	3/2	47	203	F	3/5	3	B ₄
U65	3/2	61	827-	F	3/5	3	A
U75	3/2	51	BH-22	F	3/5	3	B ₇
U165	6/8	70	109	F	6/29	21	C
U175	6/12	65	52	M	6/29	17	A
U185	6/20	57	62	F	6/29	9	B ₂

TABLE IV (continued)

**X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 11
BLOUNT**

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
U85	3/3	57	BH-92	M	3/5	2	B ₅
U95	3/9	61	944	F	3/23	14	B ₂ ?
U105	3/21	62	HB768	F	3/23	2	B ₃
U115	3/29	68	U232	F	4/2	4	B ₃
U125	4/18	68	U242	M	4/23	5	B ₂ ?
U135	4/19	64	136	F	4/23	4	B ₈
U145	4/22	54	HB117	F	4/23	1	C
U155	4/22	72	BH-62	F	4/23	1	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 12
SPRING HILL

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
M15	1/28	60	395	F	2/16	19	C
M95	2/2	61	408	F	2/16	14	B ₃
M105	2/3	65	428	M	2/16	7	B ₂ ?
M115	2/4	70	349	F	2/16	12	B ₂
M155	2/9	58	281	F	2/16	7	B ₃
M165	2/9	55	201	M	2/16	7	B ₂
M185	2/16	64	424	M	2/16	0	B ₄
M195	2/16	67	417	M	2/16	0	B ₅
M235	2/25	55	337	F	2/28	3	B ₃
M255	2/26	64	397	M	2/28	2	C?
M265	2/28	67	393	F	2/28	0	B ₃
M275	2/28	53	200	M	2/28	0	C
M295	3/10	75	17	F	3/18	8	B ₂
M305	3/14	55	684	F	3/18	4	B ₄
M315	3/14	56	684	F	3/18	4	B ₂ ?
M325	3/19	65	427	F	4/13	25	NR
M385	4/28	50	193	F	5/12	14	B ₂ ?
M415	6/4	68	93	M	6/24	20	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 13
SPRING HILL

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
M25	1/28	50	412	F	2/16	19	C
M45	1/30	60	394	F	2/16	17	C?
M55	1/30	65	208	M	2/16	17	C
M65	1/30	80	391	F	2/16	17	B ₂
M85	2/1	60	56	M	2/16	15	C
M125	2/5	62	733	F	2/16	11	C
M135	2/6	60	423	F	2/16	10	C?
M145	2/7	85	252	F	2/16	9	B ₂ ?
M175	2/12	55	416	F	2/16	4	C?
M205	2/17	60	402	M	2/28	11	NR
M225	2/23	72	422	M	2/28	5	NR
M285	3/4	59	400	F	3/18	14	C
M345	4/4	65	335	M	4/13	9	C
M355	4/4	67	341	M	4/13	9	B ₂
M365	4/21	62	251	M	5/12	21	C
M395	5/2	55	13	M	5/12	10	B ₂
M405	5/7	70	74	M	5/12	5	C

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 14
GREENEVILLE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
T551	2/6	67	51	F	2/11	5	NR
T553	2/11	65	25	F	2/21	10	B ₂ ?
T554	2/13	65	112	F	2/14	1	B ₂
T555	2/14	64	41	F	2/21	7	B ₂
T558	2/17	74	22	M	2/21	4	B ₂
T5515	2/24	75	53	F	3/7	11	B ₂
T5516	2/25	58	42	F	3/7	10	B ₂
T5520	2/27	66	23	M	3/7	8	B ₂ ?
T5521	2/28	71	32	F	3/7	7	C?
T5524	3/8	54	57	F	3/21	13	C
T5525	3/9	50	291	F	3/21	12	B ₃
T5526	3/11	70	56	F	3/21	10	C
T5527	3/11	69	26	F	3/21	10	C?
T5529	3/16	58	31	F	3/21	5	C?
T5530	3/19	63	21	F	3/21	2	C
T5536	4/5	60	306	M	4/11	6	B ₂
T5537	4/25	76	35	F	5/6	11	C

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 15
GREENEVILLE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
T552	2/10	46	-112	F	2/11	1	A
T556	2/14	59	58	F	2/21	7	B ₂
T557	2/16	74	28	M	2/21	5	B ₂ ?
T559	2/17	67	44	M	2/21	4	B ₂
T5510	2/17	70	32	M	2/21	4	B ₂
T5511	2/18	49	299	F	2/21	3	B ₂
T5512	2/19	71	311	M	2/21	2	B ₃
T5513	2/22	75	33	F	3/7	13	B ₂
T5514	2/24	65	-102	F	3/7	11	B ₃
T5517	2/25	70	54	M	3/7	10	B ₂ ?
T5518	2/25	72	308	F	3/7	10	B ₂
T5519	2/26	66	34	M	3/7	9	B ₂
T5522	3/3	66	8	M	3/7	4	C
T5523	3/5	67	37	F	3/7	2	B ₃
T5531	3/21	79	24	M	4/11	21	B ₂ ?
T5532	3/23	70	52	M	4/11	19	B ₂ ?
T5533	3/24	70	142	M	4/11	18	C?
T5535	4/1	75	10	F	4/11	10	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 16
OAK RIDGE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
1174	3/3	-	-28	F	3/10	7	C
1188	3/7	-	40	M	3/10	3	A
1209	3/15	-	26	F	3/24	9	C
1218	3/21	-	-45	M	3/24	3	B ₄
1226	3/23	-	-10	F	3/24	1	B ₃
1227	3/23	-	12-	M	3/24	1	B ₃
1234	3/31	-	35	M	4/7	7	B ₂
1235	3/30	-	-6	M	4/7	8	C
1236	3/30	-	2	F	4/7	8	C?
1253	4/8	-	-9	F	4/21	13	A
1261	4/16	-	-15	M	4/21	5	C?
1268	4/19	-	-1	F	4/21	2	C
-	3/25	-	-	F	-	-	A ^a

^aThis calf died and was disposed of before X-rays could be made. It was classified as A from dwarf characteristics.

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 17
OAK RIDGE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
1064	2/7	-	741	M	2/22	15	C?
1070	2/13	-	568	M	2/22	9	C?
1110	2/19	-	-2	F	2/22	3	B2?
1185	3/7	-	572	F	3/10	3	C
1195	3/10	-	481	F	3/24	14	B2?
1196	3/10	-	237	M	3/24	14	C
1200	3/10	-	500	F	3/24	14	C?
1208	3/14	-	540	F	3/24	10	B3
1223	3/23	-	-61	M	3/24	1	B2
1248	4/6	-	-53	F	4/21	15	C
1263	4/17	-	735	F	4/21	4	C
1264	4/17	-	528	F	4/21	4	B2
1273	4/22	-	597	F	5/3	11	NR
1283	4/30	-	210	F	5/3	3	B2

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 18
OAK RIDGE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
1072	2/13	-	-47	F	2/22	9	B ₂ ?
1080	2/14	-	654	F	2/22	8	C?
1098	2/15	-	297	F	2/22	7	B ₃
1102	2/18	-	333	F	2/22	4	C?
1107	2/19	-	476	M	2/22	3	C?
1128	2/21	-	52	F	2/22	1	C?
1132	2/21	-	165	F	2/22	1	B ₂
1136	2/22	-	157	M	3/10	16	C
1146	2/24	-	630	M	3/10	14	C
1149	2/26	-	415	F	3/10	12	C
1154	2/27	-	376	M	3/10	11	C
1157	2/27	-	-27	F	3/10	11	B ₂ ?
1162	2/28	-	635	F	3/10	10	C
1167	3/2	-	426	M	3/10	8	C
1175	3/4	-	-26	F	3/10	6	C
1178	3/5	-	364	M	3/10	5	C
1192	3/8	-	403	M	3/10	2	C
1203	3/12	-	128	M	3/24	12	C
1229	3/24	-	612	F	4/7	14	C?
1230	3/26	-	522	F	4/7	12	C

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 19
OAK RIDGE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
1084	2/15	-	485	F	2/22	7	B ₄
1085	2/15	-	430	M	2/22	7	B ₂ ?
1086	2/15	-	624	F	2/22	7	C
1092	2/16	-	169	F	2/22	6	C
1117	2/20	-	15	F	2/22	2	B ₂
1127	2/21	-	349	F	2/22	1	B ₂ ?
1129	2/22	-	-52	F	2/22	0	B ₃
1138	2/23	-	648	M	3/10	15	C
1144	2/25	-	-30	F	3/10	13	C
1150	2/26	-	458	M	3/10	12	B ₄
1151	2/26	-	656	M	3/10	12	C
1155	2/27	-	81	F	3/10	11	B ₂ ?
1156	2/27	-	554	F	3/10	11	C?
1158	2/27	-	595	F	3/10	11	B ₃
1160	2/28	-	524	M	3/10	10	B ₇
1161	2/28	-	634	M	3/10	10	B ₂ ?
1163	2/28	-	350	F	3/10	10	B ₂ ?
1165	3/1	-	347	M	3/10	9	C?
1166	3/1	-	368	F	3/10	9	C
1169	3/2	-	101	F	3/10	8	B ₃
1177	3/5	-	527	F	3/10	5	B ₃
1217	3/20	-	170	M	3/24	4	B ₂

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 20
OAK RIDGE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
1068	2/11	-	550	M	2/22	11	B ₂
1073	2/13	-	653	F	2/22	9	C
1090	2/16	-	196	F	2/22	6	C
1091	2/16	-	86	F	2/22	6	C
1096	2/17	-	600	F	2/22	5	C
1100	2/17	-	-141	F	2/22	5	B ₂ ?
1108	2/19	-	204	M	2/22	3	C
1116	2/19	-	482	M	2/22	3	C
1139	2/24	-	362	F	3/10	14	C
1159	2/28	-	122	F	3/10	10	C
1164	2/28	-	-11	F	3/10	10	C?
1168	3/2	-	652	F	3/10	8	C
1179	3/6	-	448	F	3/10	4	B ₂
1189	3/7	-	126	M	3/10	3	B ₂
1204	3/13	-	396	F	3/24	11	C
1207	3/14	-	328	M	3/24	10	C
1213	3/18	-	-135	F	3/24	6	C?
1215	3/18	-	31	M	3/24	6	C?
1221	3/22	-	651	M	3/24	2	C
1222	3/22	-	410	M	3/24	2	C

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 21
OAK RIDGE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
1101	2/18	-	340	F	2/22	4	C
1111	2/19	-	-29	F	2/22	3	B2
1119	2/20	-	92	F	2/22	2	B3
1123	2/21	-	-24	F	2/22	1	B3
1224	3/23	-	-583	F	3/24	1	C
1243	3/31	-	677	F	4/7	7	C?
1247	4/5	-	779	F	4/7	2	B3
1259	4/13	-	24-	F	4/21	8	B2
1275	4/22	-	-185	M	5/3	11	NR
1276	4/22	-	HB25	F	5/3	11	C
1279	4/26	-	-170	F	5/3	7	C
1285	5/2	-	-137	F	5/3	1	B2
1296	5/9	-	-187	M	5/17	8	B2
1299	5/11	-	-247	M	5/17	6	B2

TABLE IV (continued)

**X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 22
SPRINGFIELD**

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
H945	1/5	60	124	F	2/15	41	B ₂ ?
H965	1/19	54	143	F	2/15	27	C
H045	3/22	71	532-	M	3/29	7	C
H075	4/19	69	643-	M	5/11	22	C?
H085	4/19	58	623-	F	5/11	22	C

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF HEREFORD BULL 23
SPRINGFIELD

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
H955	1/16	68	438	M	2/15	30	B ₂ ?
H975	1/26	67	482-	M	2/15	20	C?
H985	1/28	60	HB2	F	2/15	18	C?
H995	2/9	61	40-	F	2/15	6	B ₂
H015	3/4	65	38-	M	3/19	15	C
H025	3/9	71	521	F	3/19	10	C?
H035	3/18	84	51-	M	3/19	1	B ₂ ?
H055	4/2	75	522-	M	4/13	11	C?
H095	4/20	78	81T	M	5/11	21	C
H105	4/24	53	4	F	5/11	17	C
H115	5/1	75	462-	F	5/11	10	C
H125	5/22	86	1	M	5/30	8	C
H135	6/9	71	53	M	6/24	15	C

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF ANGUS BULL 24
BLOUNT

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
U15	1/23	68	W23	M	1/29	6	B ₂
U25	1/27	52	72	M	2/3	7	C?
U35	1/28	54	21	F	2/19	22	B ₃
U45	2/1	59	18	M	2/3	2	B ₂
U55	2/4	61	80	F	2/19	15	C?
U65	2/8	67	51	M	2/19	11	B ₂ ?
U75	2/11	60	20	M	2/19	8	B ₂
U85	2/11	60	2109	F	2/19	8	B ₂
U95	2/13	61	61	F	2/19	6	B ₃
U105	2/13	62	63	F	2/19	6	C?
U115	2/14	58	321	F	2/19	5	B ₂
U125	2/25	57	16	M	3/5	8	B ₂ ?
U135	2/26	62	1110	F	3/5	7	B ₃
U145	3/1	59	15	M	3/5	4	C?
U155	3/5	59	331	F	3/23	18	C
U165	3/22	75	50	M	3/23	1	C
U175	4/5	68	1701	M	4/23	18	B ₂
U185	4/9	55	62	F	4/16	7	B ₃

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF ANGUS BULL 25
CROSSVILLE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
P15	2/9	65	45	M	2/28	19	C?
P35	2/16	60	22	F	2/28	12	C
P95	2/26	58	21	M	2/28	2	B ₂
P105	2/28	64	52	M	2/28	0	C
P125	3/1	54	63	F	3/17	16	C
P155	3/2	64	50	M	3/17	15	C
P165	3/2	48	54	F	3/17	15	B ₃
P175	3/3	52	24	M	3/17	14	C
P175H	3/3	48	24	F	3/17	14	C
P185	3/3	54	40	F	3/17	14	B ₃
P195	3/3	57	62	M	3/17	14	C
P205	3/3	57	47	M	3/17	14	C?
P235	3/4	60	53	F	3/17	13	C?
P245	3/4	67	35	M	3/17	13	C?
P265	3/7	65	51	M	3/17	10	B ₂
P275	3/8	65	37	F	3/17	9	C
P295	3/14	72	43	M	3/17	3	C
P305	3/14	56	36	M	3/17	3	B ₂
P315	3/9	60	61	F	3/17	8	B ₃
P325	3/18	70	39	F	3/31	13	C
P345	3/19	74	34	M	3/31	12	C
P365	3/21	64	30	F	3/31	10	B ₂
P375	3/24	70	38	M	3/31	7	B ₂
P405	3/28	60	42	M	3/31	3	B ₂
P415	3/28	65	46	M	3/31	3	B ₃
P445	4/10	65	56	F	4/14	4	C
P455	4/11	68	49	F	4/14	3	B ₂
P525	5/11	64	57	M	5/30	19	C?

TABLE IV (continued)

X-RAY CLASSIFICATION OF PROGENY OF ANGUS BULL 26
CROSSVILLE

Tattoo	Birth Date (1955)	Birth Weight (Lbs.)	Number of Dam	Sex	X-Ray Date (1955)	Age at X-Ray (Days)	X-Ray Class.
P25	2/9	35	8	F	2/28	19	NR
P45	2/21	46	76	F	2/28	7	C
P55	2/23	46	28	F	2/28	5	NR
P65	2/24	54	9	M	2/28	4	B ₃
P75	2/25	52	26	M	2/28	3	C?
P85	2/25	55	12	F	2/28	3	C
P115	2/28	47	88	F	2/28	0	B ₂
P135	3/2	55	5	F	3/17	15	C
P145	3/2	55	7	M	3/17	15	C?
P215	3/3	60	80	M	3/17	14	C
P225	3/3	56	55	F	3/17	14	B ₂ ?
P255	3/6	60	1	M	3/17	11	B ₂
P265	3/8	56	6	M	3/17	9	B ₂ ?
P335	3/19	54	13	F	3/31	12	B ₂
P355	3/19	52	15	F	3/31	12	C
P385	3/26	68	3	M	3/31	5	C?
P395	3/28	48	4	M	3/31	3	B ₂
P425	4/3	58	31	M	4/14	11	C
P435	4/3	65	11	M	4/14	11	C?
P465	4/2	47	85	F	4/14	12	C
P475	4/14	46	86	F	4/14	0	C?
P485	4/27	60	10	M	5/11	14	C
P495	4/30	57	84	F	5/11	11	C?
P505	4/30	57	87	M	5/11	11	B ₂ ?
P515	5/5	50	16	M	5/11	6	C?