AN EVALUATION OF THE X-RAY METHOD FOR DETECTING CARRIERS OF THE SNORTER DWARF GENE IN BEEF CATTLE

By

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Scope of Study: In an attempt to determine the accuracy of the X-ray method for distinguishing dwarfism genotypes, radiographs were made of the lumbar vertebrae of over 1500 calves produced in three beef cattle research projects including several lines of Hereford and Angus cattle. The radiographs were classified as to degree of abnormality of the lumbar vertebrae, and genotype predictions were made from these classifications. Calves with normal vertebrae were classified as C and predicted to be homozygous normals. Calves with extremely abnormal vertebrae were classified as A and predicted to be dwarfs. Calves showing intermediate degrees of abnormality were classified from B_1 through B_8 and predicted to be dwarf carriers. Eighty-five animals of known genotype for dwarfism were X-rayed; and 53 X-rayed bulls were progeny tested by matings to dwarf carrier cows. Almost 400 calves were X-rayed in herds presumed to be free of the dwarf gene.

Findings and Conclusions: Of 36 animals known to be heterozygous for the dwarf gene, 77.8 percent were classified as B, and 22.2 percent were classified as C. Of 317 calves presumed to be dwarf free, 74.4 percent were classified as C, and 25.6 percent were classified as B. Of 49 phenotypic dwarfs, 96 percent were classified as A, and 6 percent were classified as B_8. The following estimates of accuracy for the X-ray method are indicated: (1) 78 percent accurate in identifying dwarf carrier animals; (2) 74 percent accurate in identifying dwarf free animals; (3) 96 percent accurate in identifying dwarfs.

The frequency of the mild abnormalities seen in X-rays of calves from presumed clean herds was found to vary between herds of different genetic makeup and between different sire groups in the same herd. It was concluded that these abnormalities seem to be controlled by hereditary factors other than the dwarf gene. Highly significant ($P < .005$) sex differences were found within B and C X-ray classifications. With the degrees of abnormality scored one to nine, the males averaged 2.31, while the females averaged 1.79. These sex differences could not be explained.

It was concluded that the X-ray method is highly accurate in identifying dwarf calves, but is not highly accurate in distinguishing between carriers and non-carriers of the dwarf gene among normal animals.

ADVISER'S APPROVAL ______________________________

AN EVALUATION OF THE X-RAY METHOD FOR DETECTING CARRIERS OF THE SNORTER DWARF GENE IN BEEF CATTLE

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INTRODUCTION

During the late 1940's and early 1950's a hereditary type of dwarfism became a problem of major proportions to breeders of Hereford and Angus cattle. Prior to this time, other forms of cattle dwarfism had been encountered, but none had caused as much concern and discussion as did this recessive trait which became known as the "snorter," "short-headed," or "brachycephalic" dwarf.

The problem became apparent with the greatly increased occurrence of dwarf calves among the progeny of cattle which themselves appeared normal. These dwarfs represented a real economic loss, since they grew very slowly and often died soon after birth. However, the money lost because of the relatively low value of the dwarf animals themselves was but little compared to that lost from the sacrifice of many good breeding animals which were culled because they were related to dwarfs. After the inheritance of the dwarf anomaly became established, breeders, for want of a sure way to distinguish between dwarf carrier animals and dwarf free animals, were forced to select breeding stock from only those lines that were believed to be free of the dwarf problem. Consequently, animals with ancestors that had produced dwarfs were discriminated against to the extent that they were worth little more than their slaughter value.

Since the numbers discriminated against represented a fairly large fraction of the population, many outstanding individuals which were dwarf free were included. These were discarded from the breeding population along with those that actually did carry the dwarf factor. So the damage caused by dwarfism was not only economic, but loss of valuable genetic material retarded the overall progress of the breeds.

Soon after dwarfism was realized to be a problem, research was initiated in the area of developing methods for distinguishing between carriers and non-carriers of the dwarf factor among normal appearing animals. Hematological and anatomical differences have been studied extensively for this purpose, but no completely accurate quick-test method has been found. Several techniques have proven mildly successful, but as yet no test has given results accurate enough to overcome the pedigree barriers. The progeny test is accurate, but it is very slow and extremely expensive.

This study is an evaluation of results obtained using the X-ray method of detecting dwarf carriers suggested by Iowa workers (Emmerson and Hazel, 1956). These data represent a five-year period in which the X-ray technique was tested at the Fort Reno Agricultural Experiment Station.

REVIEW OF LITERATURE

Dwarfism in Cattle

Reports of various types of hereditary dwarfism in cattle have appeared periodically in the literature since the turn of the century. Many of these reports deal with observations of dwarfs made on ranches and farms with no actual breeding tests made to determine the mode of inheritance. In other cases, especially where a type of dwarfism caused a definite economic problem, extensive breeding studies were made and the inheritance established. Since this study is concerned primarily with only one of these more important types, the following review of literature on dwarfism in cattle is subdivided into two parts: (1) Recessive "snorter" dwarfism and (2) Other types of dwarfism in cattle.

Recessive "Snorter" Dwarfism

In the past decade a recessive dwarf commonly referred to as the "snorter" has been a serious economic problem to purebred breeders of Hereford and Aberdeen-Angus cattle. This form has also been referred to as the "shortheaded" or "brachycephalic" dwarf. Among the earlier papers reporting this condition are those by Johnson *et al.* (1950), Lindley (1951) and Gregory *et al.* (1951). Since then the condition has received considerable study and has been described by several other workers. The gross anatomy of the snorter dwarf is quite variable both within and between breeds. Usually the dwarf is distinguishable at birth, but in some cases the abnormalities have not become evident until three or four weeks of age. In the dwarf, body size is reduced, and there is a general shortening and thickening of the long bones. In some cases, the legs are distorted and the pasterns, flexed. Certain abnormalities of the skull are described by Gregory et al. (1951, 1952, 1953) and Gregory and Brown (1952). There is a marked convexity of the frontal bones of the calvarium associated with a hydrocephalic tendency. The forehead is bulging and the face, dished-in. There is disproportion between the upper and lower jaw, resulting in an undershot condition with malocclusion of the incisors with the dental pad. In most cases the tongue is large and protrudes from the mouth, and there may be protrusion of the eyes, accompanied by a glassy stare (Lindley, 1951; Pahnish et al., 1955c). Heavy breathing may not be present immediately after birth, but usually develops by two months of age, and it is particularly noticeable after violent exercise (Gregory et al., 1951; Carroll et al., 1951). This labored, noisy breathing is the origin of the term "snorter" for this type of dwarf. A pot-bellied appearance develops early in life and bloat is very common, especially in older dwarfs (Johnson et al., 1950; Carroll et al., 1951; Gregory et al., 1951; Pahnish et al., 1955c). Sexual activity is impaired in bulls and cows, and parturitions are very difficult in those heifers that do conceive (Pahnish et al., 1955b).

Although other theories have been advanced, the bulk of proof from breeding tests and post-probant studies indicates that the mode of inheritance of the snorter dwarf anomaly in the beef breeds is a single autosomal recessive gene (Lush and Hazel, 1952, 1955; Gregory et al., 1953; Pahnish et al., 1955a; Chambers et al., 1954a). This type of inheritance was first suggested by Johnson et al. (1950), although at that time no breeding tests had been made. They termed the snorter dwarf gene a latent lethal, since the animals seldom reach breeding age. It was suggested that the heterozygote is somewhat intermediate in type. Gregory et al. (1951) concluded that dwarfism is conditioned by a single autosomal recessive gene, from their post-probant studies of dwarf frequencies.

Lush and Hazel (1952) analyzed a large amount of breeders' data collected by the American Hereford Association and reported that the data indicated the dwarf gene behaved as an autosomal recessive. The results of matings of known carrier dams to known carrier bulls are given below:

	Observed		Expected	
Total Matings	Normal	Dwarf	Normal	Dwarf
266	197	69	199.5	66.5

These results very closely approach the 3:1 ratio of normals to dwarfs expected if dwarfism is controlled by a simple recessive factor. In order to remove bias inherent in such records, they eliminated from the study the first dwarf calf and all calves preceding it, produced by each bull and cow used. The first dwarf furnished evidence that the parent was a carrier, and all later calves were used in the data presented above.

Pahnish et al. (1955a) confirmed this mode of inheritance by a series of critical breeding tests. These workers took precautions to avoid confusion with comprest dwarfs. In test matings of known carrier bulls with known carrier cows, the following results were observed:

Total Calves	Observed		Expected		Chi-square
	Normal	Dwarf	Normal	Dwarf	
90	66	24	67.5	22.5	0.059

The sex ratio of Hereford dwarfs was found to be 1:1. The following data were collected from several herds:

Total No. Dwarfs	Observed		Expected		Chi-square
	Male	Female	Male	Female	
244	127	117	122	122	0.332

From five matings of dwarf X dwarf, all calves were dwarfs. From six matings of dwarf X heterozygote, two normal calves and four dwarf calves were produced. Additional data of this type are furnished by Lush and Hazel (1955) who reported 30 normal and 11 dwarf calves from carrier X carrier matings, which closely approaches the theoretical 3/4 normals and 1/4 dwarfs.

A different mode of inheritance was theorized by workers in California, after making several crosses between various types of dwarfs (Gregory, 1955, 1956; Gregory et al., 1957). Their hypothesis is that bovine dwarfism is a complex of several components rather than a single entity, and each component is homozygous for the same autosomal recessive gene. Matings of Hereford dwarfs X Angus dwarfs produced short-headed dwarfs and phenotypically normal calves that resembled comprest animals in size; Shorthorn dwarfs X Hereford dwarfs produced normal calves which were comprest in type; Shorthorn dwarfs X Angus dwarfs produced one short-headed dwarf and one comprest normal; and a different Shorthorn dwarf X Hereford normals (some dwarf-carriers) produced short-headed dwarfs and some phenotypic normals (Gregory, 1955). A similar array of offspring was reported by Gregory (1956) from intercrosses between short-headed (snorter) dwarfs, long-headed Angus dwarfs, and two types of Shorthorn dwarfs designated Shorthorn III_A and Shorthorn III_B. Gregory et al. (1957) mated a Hereford bull to comprest cows of snorter dwarf-carrier stock, snorter dwarf cows and normal dwarf-carrier cows. Among these offspring he recognized brachycephalic (snorter) dwarfs, intermediate dwarfs, comprests, and normals. In these reports, the parent types are not well-defined in some of the crosses, nor are the criteria for classifying calves. Although interesting, this theory cannot displace that of a single autosomal recessive factor, in view of the supporting evidence.

The same recessive gene is responsible for snorter dwarfism in the Hereford and Angus breeds (Chambers et al., 1954a; Gregory, 1955; Gregory and Carroll, 1956; Dollahon et al., 1957). All these workers reported the production of Angus X Hereford crossbred dwarfs. Snorter dwarfs may occur in other breeds, but are relatively rare, and have not become a problem in these breeds. Gregory and Carroll (1956) presented morphological evidence that the same dwarf gene exists in the Shorthorn and Holstein breeds. Dollahon et al. (1957) reported a mating of snorter Hereford X midget Brahman which produced a dead calf that was believed to be a snorter dwarf.

Some attention should be directed to the question - why did snorter dwarfism become such a problem. With the type of inheritance previously discussed, elimination of the recessive homozygote (dwarf) alone should keep the frequency of the dwarf gene at a very low level. Yet, it is known that the frequency of the dwarf gene approached or exceeded 10 percent in some herds during the period when the problem was at its height (Warwick, 1958). The reason for an increase in frequency to the point where dwarfism posed a serious economic problem has not been completely determined; however, two possibilities have been considered. It is possible that the dwarf gene could have been selected for accidentally, if by pure chance the gene happened to be present in a few particularly popular sires. According to Warwick (1958), the bulk of evidence indicates this was not the case, although it cannot be completely discounted. The second possibility, suggested by several workers, is that the dwarf gene has some effect on the heterozygotes, causing breeders to favor them in selection (Johnson _et al._, 1950; Lush and Hazel, 1952, 1955; Chambers _et al._, 1954a). This possibility is also supported by recent anatomical studies showing that carrier animals are on the average shorter in cannon bone length, shorter in body, and have shorter heads than those probably free of the dwarf gene (Arthaud _et al._, 1957; Bovard _et al._, 1956).

Other Types of Dwarfism in Cattle

In order for any mutant gene to increase much in frequency, there must be selection, natural or otherwise, favoring the mutant types. It seems that breeders' preference for animals heterozygous for certain dwarf genes produced quite a problem in at least three instances where heterozygote X heterozygote matings finally exposed the nature of the gene.

The Dexter breed of cattle, described by Crew (1923) and probably originating as a cross between native Irish Kerry (black) and Red Devon, is believed to be heterozygous for a dwarf gene which in the homozygous state produces a deformed, stillborn calf. The Dexter was described as having a short, broad head with great width between the eyes and a large muzzle with distended nostrils. The shoulders are of medium thickness; the hips are wide; the quarters are deep and thick; the loin is wide; and the underline is straight. The legs are short, strong and well placed under the body, and the body is close to the ground. The color of the Dexter is either black or red and weight specifications for bulls were not over 900 pounds, and for cows, not over 800 pounds. Occasionally two undesirable characteristics were encountered - "bad tailhead" (tail originating too far up the back and arching upwards and backwards) and a combination of bent forelegs with inwardly turned hoofs.

In attempting to develop a true breeding line, breeders mated Dexters to Dexters and found that from five to thirty percent of the offspring from such crosses were abnormal, stillborn calves. Crew described these stillborn calves as follows: "The abnormalities which these stillborn calves exhibited were constant, and so characteristic that the fetus is known as a "bull-dog" calf. The cranium is bulging, the nose markedly depressed, the lower jaw protruding, the upper lip is slit, baring the teeth, while the swollen tongue, thrust far out, curls up over the nose. Owing to the disproportionate development of the buttocks, the tail seems to have its origin far up on the back; usually there is a gaping deficiency of the abdominal wall through which the intestines pass to form a large umbillical hernia. The skin hangs loosely in folds; there is abundant subcutaneous fat. The limbs are ridiculously short and the digits unusually separated."

According to Crew, the Dexter X Dexter matings produced four classes of calves in such proportions as to suggest that the Dexter was a Mendelian di-hybrid in respect to color and size. He proposed a mode of inheritance in which the Dexter type was produced by one gene, S, the action being intensified by two independent mutations linked to the S gene (S,L_1L_2). Therefore the "bull-dog" calf would be $(S,L_1L_2)(S,L_1L_2)$, omitting the genes for color. However, the mode of inheritance generally considered to be correct was advanced by Hutt (1934), who stated that the Dexter X Dexter matings produced one-fourth "bull-dog" calves and also long-legged Kerry-type cattle as well as Dexters. The Dexter type was apparently due to the heterozygous state of a partially dominant gene which caused the short legs and short, broad head. Segregation of genes produced the "bull-dog" dwarf, homozygous for the character, and the Kerry-type animal which lacked the gene entirely.

A similar more recent situation arose with the increase in popularity of "compress" Herefords. Forbes (1946) details a glowing description of compress Herefords, emphasizing their low-setting, bulging quarters, short wide bodies, thick necks and attractive heads. There was a general increase in selection for this type of animal, greatly accelerated by showring preference, especially in the fat steer classes. According to Stonaker et al. (1952) the winnings of the compress type began in 1941 with the grand champion steer at the National Western Livestock Exposition, Denver, Colorado. Following that, animals of the compress type won many of the steer shows throughout the country.

The presence of a dwarf gene in compress Hereford cattle was reported by Stonaker (1954) upon producing at least one dwarf calf from each of five compress bulls mated to compress cows. Compress X normal matings resulted in 50 compress and 55 normal offspring, closely approximating a 1:1 ratio. The dwarf calves were generally badly crippled or "crooked-legged." There was a difference in wither height of 4.2 inches between dwarf and normal calves and 2.5 inches between compress and normal calves from compress X compress matings. This type of dwarfing, according to Stonaker, was due to a single, partially dominant gene with CC dwarf, Cc compress, and cc normal. A chi-square test on the offspring of 107 compress X normal matings and 44 compress X compress matings did not refute his hypothesis. He concluded that the compress type of dwarfism was suggestive of the dwarfing action found in the Dexter breed.

From the results of 45 compress X compress matings, Chambers et al. (1954b) reported 11 dwarfs out of 37 calves produced. Three of the dwarf calves were of the "crooked-legged" type, five of them were straight-legged, and three were very extreme stillborn calves. Four early stage abortions or resorptions were known to have occurred. Two Hereford bulls of non-compress breeding and one Angus bull, all known carriers of the snorter dwarf gene, were bred to 24 compress Hereford cows and seven of their yearling heifers. Of 27 calves dropped, six were dwarfs, all of the typical snorter type. One resorption or abortion occurred during early pregnancy. Five of the snorter dwarfs were Herefords and one was a Hereford-Angus crossbred. They concluded that the genes causing snorter dwarfs and compress (crooked-legged) dwarfs were either allelic or that the compress cattle in this test carried the snorter dwarf gene at a high frequency.

Extreme Dexter-type dwarfs in the Shorthorn breed were observed by Stonaker (1954), resulting from compact X compact matings. In a previous study of compact Shorthorns, he had found no such dwarf calves produced (Stonaker and Tom, 1944). The compact Shorthorn was described as a small, thick, shortlegged type. They are distinguishable at birth due to their compactness, and this trait remains throughout life. Some of the animals have a tendency to be heavy in the shoulders and a bit crooked in the legs. Since some of these traits were popular in the showring at that time, several breeders attempted to concentrate the blood of this type. In the early study Stonaker and Tom (1944) suggested that the compact trait was due to a single dominant gene since no compact calves had been produced from previous standard X standard matings, and compact X compact matings had not yet produced a dwarf. However, after observing extreme dwarfs from compact X compact matings, Stonaker (1954) concluded that this type of dwarfism was similar to the Dexter "bull-dog" type reported by Crew (1923).

Several other dwarf types have been observed which, to varying degrees, have received less attention than those already mentioned. This may have been due to the very low numbers in which they occurred, because of accurate selection against the dwarf gene. In other cases, no great problem developed because the phenotypic expression of the trait was not severe and did not "cost" the breeders as much.

A recessive lethal form of dwarfism appeared in the Telemark breed of Norwegian cattle (Wriedt, 1930). This condition was compared to the "bull-dog" dwarf described by Crew (1923), but was found to differ in two important aspects. First, the heterozygote could not be distinguished from the normal homozygote; and second, the Telemark dwarf was generally born alive while the "bull-dog" was stillborn. The gene responsible was considered strictly recessive, having no effect on the heterozygote. This condition was termed a lethal because the dwarf calves all died very shortly after birth.

Lush (1930) reported the occurrence of hereditary shortleggedness in cattle on several Texas ranches. These cattle, which he called "duck-legged," were apparently normal in body with legs four to six inches shorter than normal. He proposed that this condition was the result of a single dominant gene and might be identical to the less extreme forms of dwarfness in the Dexter-Kerry cattle of Ireland, although no breeding tests were made.

A dwarf Hereford calf was examined and autopsied by workers at Oklahoma A & M College in 1924 in an attempt to find a physiological explanation for dwarfism (Craft and Orr, 1924). They observed reduced size, short irregularly curved legs, abnormally large joints, short, thickened face and a nervous disposition. At autopsy, the thyroids, parathyroids and pituitary were markedly underdeveloped. They compared these abnormalities with the human cretin and thyroidectomized animals of other species, and postulated a decreased pituitary and thyroid function as a possible cause of the dwarf condition.

Mead _et_ _al_. (1942) reported a new type of proportionate dwarfism which was found in the progeny of one sire of Jersey breeding. The dwarfs were indistinguishable from normal calves at birth and could not be definitely classified until 12 months of age. They grew more slowly, and at maturity they were 200 pounds lighter than normal cattle. This dwarf condition was attributed to a simple autosomal recessive gene.

Another recessive type of dwarfing in Jerseys was reported by Gregory _et_ _al_. (1942). The expression in the homozygote (dwarf) was more variable than in the Telemark breed of Norway (Wriedt, 1930). The bones of the skull and maxilla were affected most, and the appendicular skeleton was affected little if any. Characteristic defects noted were a short, broad head, cleft palate and other deformities of the mouth, and a slight reduction in length of leg.

A dominant type of achondroplasia was observed in a herd of grade Jersey cows (Mead et al., 1946). The mature cows were visually classified into normal and mutant types. Body measurements were taken and the mutant cows were found to be lower at the withers, shorter legged, shorter bodied, shallower chested, and smaller in the heart girth than normals. All mutant animals traced to one sire who was also of the small type. Since mutants appeared in the first calf crop of this bull and both his parents were normal, it was assumed that a dominant mutation had occurred.

Johansson (1953), in reporting the occurrence of a dominant dwarf mutant in the Swedish Red and White breed, defines achondroplasia as a general condition characterized by a defective development of the chondrous skeleton. There is a reduction in length of some or all of the long bones before birth. In some cases the head and trunk may be affected also. In these achondroplastic dwarfs he observed short, broad heads, moderately bulging foreheads, horn knobs present at birth and the upper jaws noticeably shorter than the lower. The legs were comparatively short, particularly below the knee and hock. The calves had flexed pasterns, especially noticeable on the rear legs where the toes turned completely under. This condition gradually improved with age so that the calves could walk fairly well after a week or two. The mating of one bull to unrelated cows of mixed breeding produced 25 such malformed calves (12 females and 13 males) and 28 normal calves. Of the abnormal calves, only one bull and four females were raised, and a test breeding experiment failed. It was assumed that the defective animals were heterozygous for a gene for achondroplasia that had arisen by mutation in pregerminal tissue of the sire.

Several different types of dwarfism have been observed in Florida cattle (Koger et al., 1955). Two of these types which have not been described previously are the "midget" Brahman and the "guinea." The midget Brahman is a small, compact, but otherwise normal animal that is believed to be produced by a recessive or an incompletely dominant gene of variable penetrance. The "guinea" condition occurs in crossbred and Florida native cattle and is similar in expression to comprest Herefords and midget Brahmans. These workers stated, however, that the mode of inheritance was either a dominant or an incomplete dominant gene, but apparently different from the gene in comprest Herefords. No data were presented to substantiate this. Dollahon et al. (1957) stated that the guinea appears to have descended from the Dexter. Both guinea X guinea and snorter Hereford X guinea matings produced guinea offspring, indicating a dominant or incomplete dominant gene different from the snorter gene.

Dwarfs began to appear about 1940 in a Shorthorn herd where rather intensive linebreeding was practiced (Baker et al., 1950). The dwarf had a curly haircoat, making detection possible at birth. The switch was smaller than normal in both amount and length and was responsible for the dwarf being called "stumpy." These were achondroplastic dwarfs exhibiting enlarged knees, laterally twisted cannon bones, enlarged hoof heads and turned-out feet. The length of body and the head features were normal. A tendency to become thin as age increased suggested a metabolic disturbance that becomes more pronounced as the animals mature. Breeding data indicated that the "stumpy" syndrome is caused by a single autosomal recessive gene. This gene appeared to trace back to one sire, Whitehall Sultan, and the mutation probably occurred in him or his ancestors.

Another Angus dwarf, less extreme than the snorter, was described by Baker _et_ _al_. (1951). These dwarfs were not always distinguishable from normal calves at birth. At varying ages from birth to three months, the dwarfs usually exhibited exceptionally compact, low-set, thick bodies and short, wide heads. At later ages the heads appeared noticeably longer and narrower, relatively, giving rise to the term "long-headed" for this Angus dwarf. Most of them maintained a higher degree of finish than did the stumpy Shorthorns. One calf weighed 280 pounds at 190 days; another weighed 380 pounds at 278 days; and a third weighed 630 pounds at 17½ months. The most likely conclusion seems to be that this dwarf condition is governed by a single autosomal recessive gene. Baker observed that although verbal reports that dwarf calves appeared more and more frequent within the herd indicated that some selection for the heterozygous type might take place, the results of this study did not give any statistical support to the theory.

Anatomical Research with Snorter Dwarfism

Since attempts to visually distinguish between normal animals heterozygous for the snorter dwarf gene and normal animals free of the snorter dwarf gene have failed, it seems that some method must be found to make this separation possible, before one can consider the dwarf problem solved. One area that has been investigated for this purpose is that of anatomical differences between the three dwarf genotypes. All future references to dwarf, dwarf gene and dwarfism pertain specifically to the snorter type; the word snorter being omitted in many cases to avoid needless repetition.

One of the most obvious phenotypic differences between dwarf and normal calves lies in the skeletal modifications. Of these skeletal abnormalities, the size and shape of the head has received particular attention by California workers. Gregory _et_ _al_. (1951) observed that the outstanding characteristic of dwarf calves was the brachycephalic head with marked mid-forehead prominence present at birth and persisting throughout life. He pointed out that the contour of the dwarf head was distinctive and discontinous with head contours of homozygous normal animals. Gregory and Brown (1952) reported the development of a profilometer, an instrument especially designed to reproduce the profile of the bovine head. A median head profile could be recorded on graph paper by placing the profilometer against the face of an animal and moving the contour follower and recording instrument down the length of the head.

Gregory _et_ _al_. (1952) reported that the dwarf gene in heterozygous animals had a phenotypic expression which could be detected in the median head profiles recorded with the profilometer. From preliminary field trials, they reported the correct classification of 13 heterozygous animals and four homozygous normal animals.

The profilometer was used to study head types in a large number of Hereford bulls (Gregory _et_ _al_., 1953). They reported three basic head types, depending primarily on the amount of dish in the face. Class I head type had no dish and made up only five percent of the animals studied. Classes II and III had different degrees of dishing and comprised the remaining 95 percent of the selected population. A key was constructed for differentiating the dwarf genotypes in Classes II and III. Also, discriminant functions were made, using profilometer measurements, in an attempt to increase the accuracy of the genotype predictions. According to these workers, in a field trial with 226 known carrier bulls and 21 dwarf-free bulls, predictions from head profiles were 221 carriers and 26 dwarf-free (5 errors). In summarizing their work with approximately 500 horned Hereford bulls, 325 of which were of known genotype with respect to the dwarf gene, they reported that heterozygous and homozygous normals can be differentiated with a high degree of accuracy from the relationships of three diagnostic points on the head profile. The key proved to be more accurate than discriminant functions. It should be pointed out that these trials were made on a highly-selected population.

Stonaker (1954) took head profiles of unselected bulls at the Fort Lewis Station and used the distribution of profilometer readings of their sons to test the accuracy of this method. He rejected the hypothesis that the profilometer could predict the genotype of sires and their unselected yearling sons. Schoonover and Stratton (1954) studied head profiles of Hereford heifers and reported no clear-cut evidence that a bulge or frontal bone irregularity was associated only with cows heterozygous for the dwarf gene.

Julian et al. (1956), in a study of 78 skulls of normal and dwarf Hereford cattle, reported that the spheno-occipital synchondrosis was found to close within the first week of life in dwarfs, compared to 24 to 36 months for normal cattle. In an intermediate group of normal cattle the closure occurred at 8 to 17 months. He also observed that the typical shortheadedness (prognathism) was caused by a face-shortening feature in the vicinity of the lacrimal bone. Buchanan et al. (1956) found that a certain number of snorter dwarfs showed pinching of the occipital condyles of the skull.

Many dwarfs were found to have an abnormal heart similar to the "beri-beri" heart in man and the hypertrophied heart of "brisket disease" in cattle (Eveleth et al., 1956). The dwarf heart was almost spheroid in shape, and the authors suggested this abnormality might be significant in the fact that many dwarfs die within 20 minutes after birth. The spheroid heart and abnormal skulls might prove valuable in diagnosing questionable cases of dwarfism in dead and stillborn calves.

In a study of skeletal material from 64 Hereford cattle, Tyler et al. (1956) found that certain disproportionalities exist between the appendicular skeletons of normal and dwarf animals of the same weight and age. The metacarpal bones were the most disproportionate bones in the dwarf, due largely to reduced diaphyseal length. There was evidence that a mild hypoplastic achondroplasia occurred in utero. Bovard et al. (1956) likewise reported reduced metacarpal length.

Arthaud et al. (1957) reported comparisons of body measurements taken within a week after birth from 95 pedigree-clean calves (46 bulls and 49 heifers) and 29 heterozygous calves (13 bulls and 16 heifers). Mean differences (pedigree-clean minus dwarf-carrier) in measurements within sex were: cannon bone length, 3.35 (males) and 4.09 (females); cannon width, -2.09 and -2.18; length of first five lumbar vertebrae, 2.27 and -1.56; cannon length/cannon width, 0.53 and 0.64; cannon length/cannon circumference, 0.08 and 0.07; cannon circumference, -4.36 and -3.31; and cephalic index, 0.06 and 0.04. The first three of these measurements were made from X-rays. All differences were highly significant ($P<0.01$) except cephalic index ($P<0.05$) and lumbar length ($P>0.05$). Discriminant functions for males ($Y_m = 0.100$ birth wt. + 0.492 cannon length -1.941 cannon width + 3.383 cephalic index) and females ($Y_F = -0.010$ birth wt. + 0.226 cannon length -0.581 cannon width + 5.267 cephalic index) were obtained. He reports that when these indexes were applied to the same population, the overlap was 37 percent for males and 38 percent for females. When applied to 69 X-rayed offspring of carrier parents, the overlap between B and C type calves was 79 percent for males and 24 percent for females. The significant mean differences between body measurements of dwarf gene-carrier and dwarf gene-free animals give additional support to the theory that breeders' selection tends to favor the heterozygote; but these differences could not be adapted to use in accurately diagnosing either group.

Marked differences in the lumbar vertebrae of dwarf and dwarf gene-free calves were reported by workers at Iowa State College who used these differences as the basis of a method for differentiating between the three dwarf genotypes (Emmerson and Hazel, 1956). These characteristic differences can be seen in a radiograph of the lumbar region of the vertebral column of very young calves. The vertebrae of dwarf calves show evidences of longitudinal compression such as shortened ventral surfaces, undulations on the ventral profile, absence of the dorsally arched "cup" on the ventral surface, and triangular rather than rectangular shape of the vertebral body. The vertebrae of animals free of the dwarf gene appear rectangular in outline and have a smooth ventral surface which is arched dorsally. The intermediate degree of abnormality seen in the vertebrae of dwarf gene-carrier calves varies considerably between the other two types. Emmerson and Hazel (1956) and Turman _et al_. (1957) describe a proceedure for making these radiographs with X-ray equipment, and also a method of classifying the X-rays into three dwarf types; dwarf, dwarf gene-carrier, and dwarf gene-free.

The differences found between the radiographs of the three dwarf genotypes are further elucidated by Buchanan _et al_. (1956) in a description of skeletal changes associated with dwarfism. These workers studied prepared skeletons of several dwarf types. The ventral edge of the lumbar vertebrae of the dwarf is shortened, giving the body of the vertebra a triangular rather than a rectangular outline, when viewed laterally. The cartilage located in the region of the epiphyses of these bones is enlarged and thickened as are the intervertebral discs. Thus, the bodies of the vertebrae constitute a lessened proportion of the ventral length, but the main axis of the vertebral column is maintained in a relatively straight line. Bovard _et al_. (1956) found a mean difference of 1.31 cm. in combined lumbar vertebrae length between 131 normal Hereford calves and 19 snorter dwarf calves. The measurements were taken from individual radiographs made at birth.

According to Emmerson and Hazel (1956) the compression of the body of the vertebrae occurs during the cartilaginous stage and possibly the early intramembranous stage of bone development which are in the middle and latter parts of the gestation period. In this region the very powerful longissimus dorsi and psoas major muscles, especially in the meat-type animal, exert a great part of their contractile force on these vertebrae. During the intramembranous phase of calcium deposition in the cortical part of the body of the vertebrae, the undulating or folded nature of the calcium deposits creates linear areas of increased density corresponding to the position of the areas of greatest compression. There seems to be an overall shortening of the body of the vertebrae with a corresponding increase in depth. As a result, the epiphyses do not completely cover their corresponding metaphyses. Sometimes, but not always, the metaphysis seems to be wedge-shaped in outline rather than rectangular. Julian et al. (1956) suggested that alterations of vertebrae are due to a basic growth deficiency of the primary centers of ossification in the vertebrae, consistent with the achondroplastic nature of the dwarfing process.

The commonly used X-ray classifications based on predictions of genotype are "C" (predicted clean or homozygous normal), "B" (predicted heterozygous), and "A" (predicted homozygous for the dwarf gene) (Emmerson and Hazel, 1956; Turman et al., 1957, 1958; High et al., 1958). A wide range of abnormalities fall into the B classification and these are often divided further as to degree of abnormality (Turman et al., 1957). However, calves with any degree of B classification were predicted carriers of the dwarf gene.

Hazel et al. (1956) reported that all of 40 to 50 snorter dwarfs examined by X-ray exhibited severe longitudinal compression and irregular protrusion of the body of the vertebrae below the usual epiphyseal-diaphyseal union. Many of the heterozygotes exhibited abnormalities of a less extreme nature. All of 12 normal calves having one dwarf parent had abnormal vertebrae varying from slight to extreme degrees of abnormality. From limited progeny testing of X-rayed calves, Hazel reported that some vertebral classifications do not agree with genotype. Homozygous normal animals were occasionally classified as abnormal for minor variations in vertebrae development which apparently were not associated with the snorter dwarf gene. Some heterozygotes had also been classed as having completely normal vertebrae, but this misclassification was relatively infrequent.

Turman et al. (1958) presented data on three years of study using the X-ray technique for detecting carriers of the snorter dwarf gene. Approximately 80 percent of the known dwarf carriers X-rayed as young calves at the Ft. Reno Station were correctly classified from X-rays of their lumbar vertebrae. Of 44 dwarf calves X-rayed, 42, or 95 percent, had abnormalities typical of the dwarf and were classified as A. These tests are shown in the following table:

		X-Ray Classification				
Genotype	No.	C	MB	IB	XB	A
Heterozygous:						
By progeny test	7	2	0	2	3	0
One parent dwarf	7	1	1	3	2	0
Homozygous Recessive	44	0	0	0	2	42

When calves were X-rayed in a herd believed to be free of dwarfism, approximately 77 percent were classified as C (dwarf-free) and 23 percent were classified as B (carriers). Assuming all the calves were homozygous normals, the accuracy here was 77 percent for classifying dwarf-free calves. The distribution of X-rays is shown in the following table:

		Percent of All Calves in Each X-Ray Class				
No. Sires	No. Calves	C	MB	IB	XB	A
12	235	77.0	16.6	6.4	0	0

High et al. (1958), from a study of radiographs of more than 1500 calves representing several different lines of breeding in both Hereford and Angus breeds, concluded: (1) There is considerable overlap between presumed non-carrier and carrier animals within the range of normal to mildly abnormal vertebrae. Therefore the X-ray method is not highly accurate for identifications of individual animals with respect to genotype for dwarfism. (2) The X-ray method is highly accurate in identifying snorter dwarf calves. (3) Radiographs of a bull's progeny may be used as a means of screening him for dwarfism provided the dwarfism status of the cows mated to him is known.

The X-ray method has been tested by several state agricultural experiment stations, and, although all their results have not appeared in the literature, a summary of these was presented by Hazel (1957) at the Annual Technical Committee meeting of NC-1 at Crawford, Nebraska. Of 186 carriers, produced by using a dwarf parent or proven carrier by progeny test, 167 were classified B on the basis of lumbar vertebrae X-rays. From approximately 3000 animals of different lines that are pedigree-clean, an estimate of 80 percent were classified C on X-ray. These summaries provide estimates of 90 percent accuracy in classifying dwarf gene-carriers and 80 percent accuracy in classifying presumed dwarf gene-free animals.

Anatomy and Development of the Vertebral Column

Since the X-ray method of predicting dwarfism genotypes depends completely on visible manifestations of the axial skeleton of very young calves, some detailed attention should be directed toward the anatomy and embryological development of this area.

The skeletal anatomy of farm animals has been studied extensively and the gross aspects have been generally agreed upon by most workers in this field. The anatomy of the vertebral column has been reviewed and well-described by Sisson and Grossman (1953) and by Hughes and Dransfield (1953). Usually for descriptive purposes, the vertebral column is divided into five regions, according to the part of the body in which the vertebrae are situated. These regions are designated as cervical, thoracic, lumbar, sacral and coccygeal. Within a species, the regions consist of a fairly constant number of vertebrae. For example, the vertebral formula for the bovine may be written.

$$C_7\ T_{13}\ L_6\ S_5\ C_{y18\text{-}20}$$

Although the vertebrae from different regions are distinguishable, all typical vertebrae have a common structure, the parts of which are the body, the arch and the processes.

The body of the vertebra is a somewhat cylindrical mass on which the other parts are constructed. The bodies of adjacent vertebrae are connected by intervertebral fibro-cartilages. The dorsal surface of the body is flattened to form the floor of the vertebral canal and the ventral surface is rounded laterally.

The vertebral arch is constructed on the dorsal side of the body and, originally, it consists of two lateral halves. Each lateral half of the arch is cut into in front and behind by the vertebral notches. These notches of two adjacent vertebrae form the intervertebral foramina, which are the passageways for spinal nerves and vessels. The body and arch form a bony ring which encloses the vertebral foramen. The series of vertebral rings, together with the ligaments which unite them, enclose the vertebral canal which contains the spinal cord and its coverings and vessels.

Articular processes, two anterior and two posterior, project from the border of the vertebral arch. These processes have smooth articular surfaces, which fit against those of adjacent vertebrae, and the remaining surfaces are roughened for muscular and ligamentous attachment. A single spinous process projects dorsally from the middle of the arch. It varies in form, size and direction in different vertebrae. The spinous process also furnishes attachment to muscles and ligaments.

A transverse process projects laterally from each side of the arch or from the junction of the arch and the body. In the thoracic region, each has a facet for articulation with the tubercle of a rib. Muscle and ligament attachments are also found on the transverse processes. Some vertebrae also have a ventral spine or haemal arch. Mammillary processes are found in most mammals on the posterior thoracic and anterior lumbar vertebrae. These are located between the transverse and articular processes or on the articular processes. Accessory processes are sometimes present between the transverse and posterior articular processes.

The Thoracic and Lumbar Regions of the Bovine Vertebral Column

There are 13 thoracic vertebrae in the bovine and these are fairly long with the body distinctly constricted in the middle (Sisson and Grossman, 1953). The body has a thin edged ventral crest. The arch is perforated in the posterior part by a foramen, in addition to the usual notches. The transverse process is thick and strong, and bears a rounded mamillary process (except at the posterior end of the thoracic series). Each transverse process has a facet for articulation with the tubercle of a corresponding rib. The last two thoracic transverse processes do not always articulate with a rib. The spinous processes are long; the second and third being the most prominent. There is a gradual shortening towards the lumbar region. The spines slope backward, slightly at first and increasing to the tenth. The last thoracic spine is vertical and resembles the lumbar spines.

The six lumbar vertebrae are longer than the thoracic vertebrae, the fourth and fifth being the longest. The body is much constricted in the middle and expanded at either end (Sisson and Grossman, 1953; Hughes and Dransfield, 1953). The intervertebral foramina are often double in the anterior part of the series and are very large further back. The articular processes are large and more strongly curved than those of the thoracic vertebrae. The transverse processes all curve forward. Their borders are thin and somewhat irregular, and often have projections of variable size and shape. These processes are fairly long and extend laterally from the side of the vertebral arch. The first is the shortest and the length increases to the fifth, the last being considerably shorter. They are separated by considerable intervals and form no articulation with each other nor the sacrum. The spinous processes are rather low and wide, the last being the smallest.

The arthrology of the axial skeleton is summarized in a description by Hughes and Dransfield (1953). These writers state that with the exception of the atlas, every vertebrae in front of the sacrum forms three joints with each adjacent vertebrae. The first of these is a cartilaginous articulation between the vertebral bodies, the posterior end of each body being firmly united to the anterior end of the next by a disc of fibro-cartilage. Above this joint, two synovial joints, one on each side, are formed between the posterior end of each arch and the anterior end of the next. The articular surfaces of these joints are carried by the articular processes.

Each intervertebral disc is a thin plate of fibro-cartilage interposed between the concave posterior end of one body and the convex anterior end of the next. The discs are not of uniform thickness or texture. The peripheral part of each disc is dense and tough and forms an exceedingly strong bond of union between the two bodies. Towards its center, the disc is pulpy, soft and elastic. This portion is called the nucleus pulposus which permits greater freedom of movement between the two vertebrae. The vertebral bodies are consolidated by two long ligaments to which the bodies and intervertebral discs are connected serially. These are the superior longitudinal ligament which runs along the floor of the vertebral canal, and the inferior longitudinal ligament which runs along the inferior aspect of the vertebral bodies from the sacrum as far forward as the sixth thoracic vertebra.

Embryonic and Foetal Development of the Vertebral Column

The abnormalities observed in the vertebral column of dwarfs and dwarf gene-carrier animals demand that some study be directed toward the embryonic and foetal development of these areas in attempting to elucidate the cause. The general method by which bones are developed is rather widely agreed upon and the works of several writers closely agree with that of Hughes and Dransfield (1953) which provided the outline for the following description.

The vertebrae develop from the mesodern of the various serial segments into which the embryo becomes divided. These segments or somites, as they are called, quite early in development show masses of specialized cells which grow medially and surround the notochord, the primitive membranous vertebral column, and the tissue of the central nervous system which lies above it. These masses are called sclerotomes, and they soon become differentiated into two parts, anterior and posterior, between which a cleft appears. The posterior portion, whose cells are more densely arranged, sends a process medially to unite with a corresponding process from the sclerotome of the opposite side and enclose the notochord. Another process extends dorsally and laterally to the spinal cord, while a third, known as the costal process, passes ventrolaterally. In some vertebrae, these costal processes are united at their lower extremities below the notochord by a transverse bar of tissue, the hypochordal bow. In all vertebrae except the atlas, this bow soon disappears as a separate structure.

In this way, the plan of a typical vertebra is mapped out in membrane; the first process forming half the body, the second forming half the arch, and the third forming the transverse process and, in the case of the thoracic vertebrae, the rib. The vertebra is not, however, formed entirely from the posterior part of the sclerotome. The looser tissue of the anterior part of the sclerotome also grows medially towards the notochord and becomes united with the denser tissue of the posterior part of the preceding sclerotome, the tissue which lay between the anterior and posterior portions of the same sclerotome becoming converted into the intervertebral fibro-cartilaginous disc. Thus a vertebra is formed from two adjacent sclerotomes.

Centers of chondrification appear later in these membranous precursors of vertebrae, and after the vertebra has thus been moulded in cartilage, a number of centers of ossification appear in it.

In a typical vertebra ossification proceeds from three primary centers, one of which is for the greater part of the body, while each of the other two serves one-half of the arch and a small part of the body adjacent to the foot of the arch. Secondary centers appear in the cartilage at the anterior and posterior extremities of the body, forming thin discs of bone in these positions, and also at the extremities of the transverse processes. Where the spines are prominent, as in the thoracic and lumbar regions, the summits of the spines ossify as little epiphyses with separate centers.

The notochord, as mentioned before, becomes enclosed in the bodies of the vertebrae and within these it finally disappears. That portion of the notochord, however, which lies in the region of the cleft separating the two parts of the sclerotome continues to develop to a greater degree than the portions lying in the region which will become the vertebral body, and it persists in the adult as the pulpy nucleus of the fibro-cartilaginous disc.

The development of the embryonic vertebrae into bone consists of two phases. The ossification of the cartilaginous precursors of the vertebrae is called intracartilaginous or endochondral ossification. The thickening of the shaft of the vertebral body by addition of new bone to its outer surface is called intramembranous ossification, since this new bone is formed in connection with the deep layer of the periosteum and only fibrous tissue is present.

MATERIALS AND METHODS

Calves produced in three beef cattle research projects located at the Fort Reno Agricultural Experiment Station, El Reno, Oklahoma, were available for use in the X-ray studies. From 1955 through 1959, over 1500 calves were X-rayed and classified as to predicted dwarfism genotype. Table I gives a brief description of the herds represented in this study.

Project 670, "The Improvement of Beef Cattle by Application of Breeding Methods," originally consisted of four purebred lines. In 1958, the comprest Hereford line was discontinued, and the cows of comprest type were added to Project 873. All lines either contain some known dwarf carrier cows or include individuals that, while never proven to be carriers, are suspected. Some carrier bulls were used in Lines I, II and IV, while all bulls used in Line III are considered to be clean, on the basis of progeny test results.

Project 873, "Evaluation of Methods for Identifying Dwarf Carriers in Beef Cattle," consists of a herd of known carrier cows that were purchased from breeders in four states for the purpose of progeny testing young bulls whose dwarfism genotypes were predicted by the X-ray method. Most of the bulls used in this "tester" herd were produced in Project 670 and were X-rayed as calves.

Project 650, "The Relation of Nutrition and Age at First Calving to Lifetime Performance of Beef Cows," consists of a grade Hereford herd

TABLE I

DESCRIPTION OF HERDS USED IN X-RAY STUDIES ON DWARFISM

Breeding	Dwarfism Status of Cows	No. Cows	Years X-Rayed	Total No. Calves X-Rayed
Project 670:				
Line 1: Purebred Angus	Some Known Carriers	60-80	1955-1959	213
Line II: Medium Type Purebred Hereford	Some Known Carriers	60-65	1955-1959	498
Line III: Large Type Purebred Hereford	Some Suspected Carriers	50-65	1955-1959	
Line IV: Comprest Purebred Hereford	Some Known Carriers	35-45	1955-1958	
Project 873				
Grade and Purebred Hereford	Known Carrier	60	1956-1959	349
Grade and Purebred Angus	Known Carrier	40	1956-1959	
Comprest Purebred Hereford	Mostly Known Carrier	20	1959	
Project 650				
Grade Hereford	Presumed Clean	150-180	1955;1956;1958	384

that is presumed to be free of dwarfism, since no dwarf has been produced even though two dwarf carrier bulls were used extensively. The bulls used in 1955 and 1956 are considered dwarf free. The 1958 bulls were produced in Project 670 and X-rayed as calves. Two of these proved to be carriers by siring dwarf calves in the "tester" herd.

Dwarf bulls were bred to a small group of normal heifers in order to produce calves of known dwarfism genotype. A greater number of such matings would have been desirable, but difficulty was experienced in finding useful dwarf bulls and getting normal heifers bred to them. A number of dwarf cows have produced offspring, both normal and dwarf, which were X-rayed. In all, over 50 phenotypic dwarfs from these and other herds have been X-rayed.

The radiographs were made at Fort Reno with a stationary Keleket type 115 A X-ray machine with a 200 milliampere, 115 kilovolt capacity. Exposures were made on 8 X 10 cassettes with fast speed screens, using a Bucky diaphragm grid. In making the exposures, tube to target distance was constant at 36 inches, milliamperage was held constant at 100 M. A., and exposure time and kilovoltage were varied according to the loin width of the calf. Table II gives exposure time and kilovoltage for the common range of loin widths.

One day each week was scheduled for X-raying all calves born during that week, causing the age at X-ray to vary from one day to one week. In a few cases, calves that were missed one week were X-rayed the following week at less than 14 days of age. All calves were picked up from pasture and hauled to the X-ray building on the morning scheduled for X-raying. Before being X-rayed, the calf was laid on his right side and strapped securely to a wooden platform which could be lifted onto the

TABLE II

X-RAY EXPOSURE TIME AND KILOVOLTAGE FOR DIFFERENT LOIN WIDTHS

Loin Width (cm.)	KVP	Time (sec.)
9	58	13/20
10	59	13/20
11	60	14/20
12	61	14/20
13	62	15/20
14	63	15/20
15	64	16/20
16	65	16/20
17	66	17/20
18	67	17/20

X-ray table. Using this platform, no further restraint was required, thus reducing the danger of overexposure of personnel to the X-rays. Two left lateral exposures were made of the lumbar region of each calf; one using the kilovoltage shown in the above table, and the other with kilovoltage increased 5 KVP. Both exposures were made on the same 8 X 10 film sheet by shielding one half of the cassette with a lead plate while the other half was being exposed. The radiographs were made while the animal was quiet, and if unexpected movements occurred, additional exposures were made. The exposed film was developed by standard methods in a darkroom at the same location as the X-ray machine.

Radiographs were classified with respect to morphology of the lumbar vertebrae by a method similar to that described by Emmerson and

Hazel (1956). By this method animals with normal vertebrae were classified as C, and those with extremely abnormal vertebrae (typical of dwarf calves) were classified as A. Animals with vertebral abnormalities ranging between normal (C) and typical dwarf (A) were classified as B. The B classification was further divided into eight sub-groups, B_1 through B_8. B_1 vertebrae were only slightly abnormal and approached the normalcy of C type vertebrae. B_2 through B_8 types were progressively more abnormal in morphology, B_8 having extreme abnormalities approaching those of the typical dwarf vertebrae.

Examples of C, B and A type X-rays are given in Figure 1. The X-rays of normal or C type vertebrae show smooth ventral profiles which are arched dorsally. At each end of a vertebral body are well defined convex lobes or "shoulders." The body of the vertebra has a rectangular, bilaterally symmetrical appearance. In comparison with C type vertebrae, the bodies of the A type or dwarf vertebrae are smaller in relation to the epiphyses and have a somewhat triangular instead of rectangular shape. Very pronounced double-peaked projections on the ventral profile are usually present on all six lumbar vertebrae in A type X-rays. These downward projections are irregular deposits of calcium. The B types of vertebrae ranged in morphology between these two extremes. The B_1 classification was used for those cases with any distinguishable irregularity that prevented them from being typical C types. In most cases B_2 through B_8 had one or more vertebrae with small irregular calcium deposits on the ventral surface. B_5 through B_8 usually were somewhat triangular and had more pronounced calcium deposits.

The radiographs were classified by at least two persons working independently. For X-rays where independent classifications differed,

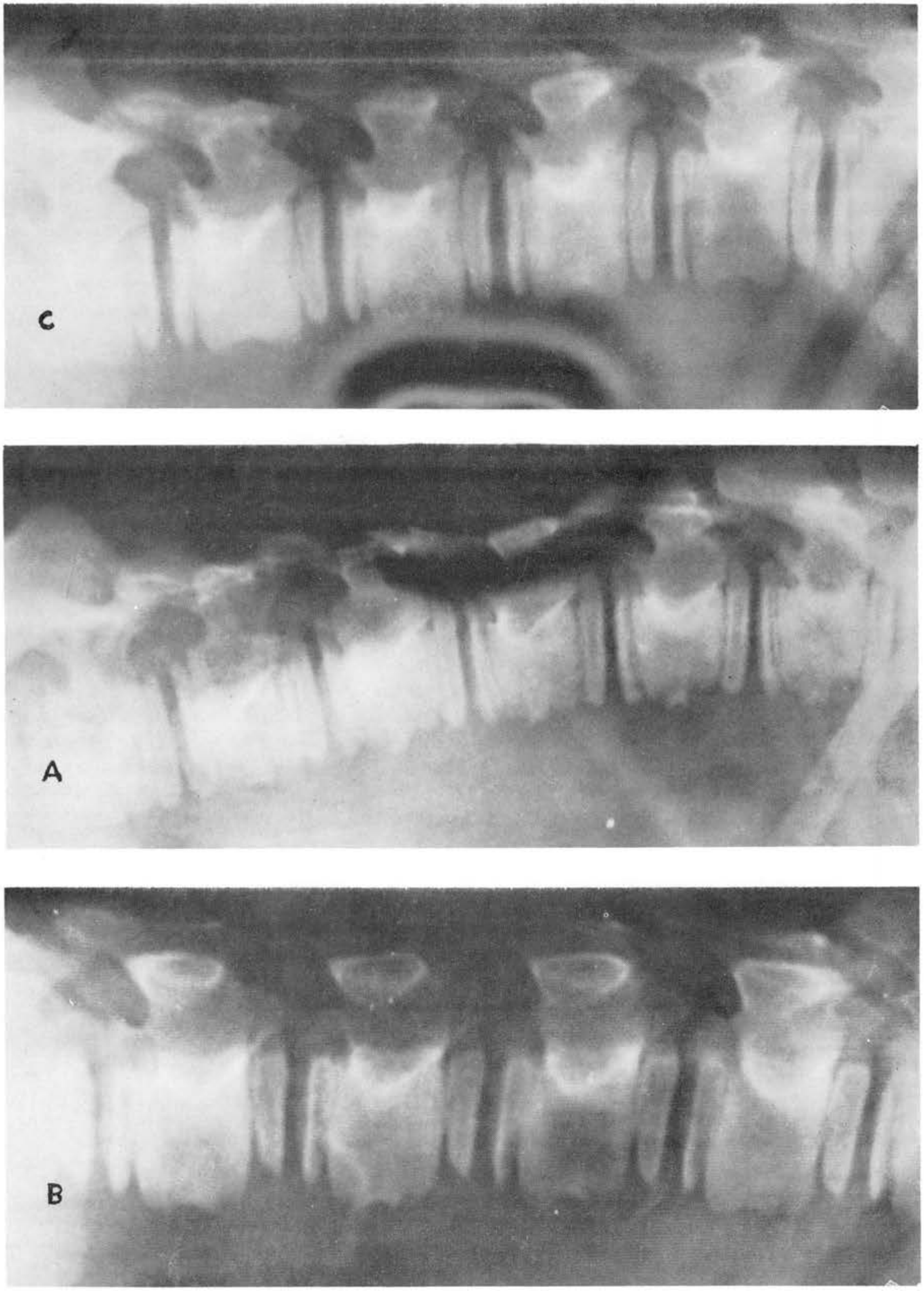

Figure 1. Lateral lumbar radiographs of the three dwarfism types. Top - Normal (Classified C). Middle - Dwarf (Classified A). Bottom - Predicted dwarf carrier (Classified B).

one classification was agreed on collectively. Most disagreement was found on X-rays that were borderline between C and B_1. The classification system is subjective, and the variation between adjacent classes seems to be continuous from C through B_8. There is a greater difference between B_8 and A X-rays than between any other two adjacent classifications. The morphology of the vertebrae of dwarfs is unique, and no non-dwarf calf has exhibited abnormalities which fit this pattern, although several have been quite extreme.

Statistical analyses of the data presented in this paper are based on methods presented by Snedecor (1956).

RESULTS AND DISCUSSION

The most precise measure of the accuracy of genotype predictions based on lumbar radiographs can be obtained by using animals of known genotype. Since snorter dwarfism seems to be controlled by a single autosomal recessive gene, there are three possible genotypes; homozygous normal, heterozygous and homozygous recessive. Of these, only the homozygous recessive (dwarf) condition can be visually identified. The only mating that will produce a known heterozygote is that of dwarf X normal, and the number of such matings has been limited by breeding difficulties, mortality of dwarfs and low reproductive ability of dwarfs. Calves that result from the mating of phenotypically normal individuals cannot be identified as to dwarfism genotype at birth unless they are dwarfs (recessive segregates from carrier X carrier matings). Of the two other genotypes possible from such matings, only the heterozygous condition can be established definitely by progeny test; i.e., by producing a dwarf. The homozygous normal male can produce enough normal calves from matings to dwarf carrier or dwarf cows to make the probability of his being a carrier extremely low, but his genotype cannot be definitely established.

The X-ray classifications of all animals of known genotype are shown in Table III. Of 23 calves known to be heterozygous at birth, 17 percent were predicted to be homozygous normal (classified C), and 83 percent were predicted to be heterozygous (classified B). Of the 13 animals that were proven heterozygous by progeny tests, 31 percent were classified C, and 69 percent were classified B.

TABLE III

SUMMARY OF X-RAY CLASSIFICATIONS OF ALL ANIMALS OF KNOWN GENOTYPE FOR THE DWARF GENE

		X-Ray Classification									
Genotype	No.	C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	A
Heterozygous											
By Progeny Test	13	4	1	2	1	-	2	-	1	2	-
Dwarf Parent	23	4	6	9	-	2	1	-	1	-	-
Total	36	8	7	11	1	2	3	-	2	2	-
Homozygous Recessive[1]	49	-	-	-	-	-	-	-	-	3	46

[1] Phenotypic dwarfs

Combining the X-ray classifications of all known heterozygotes, 22.2 percent were predicted to be homozygous normal, and 77.8 percent were predicted to be heterozygous. These predictions are less accurate than those summarized by Hazel (1957), in which 89.8 percent of 186 known carriers were classified B on X-ray. The eight C X-rays in this group are quite normal in appearance and cannot be distinguished from C X-rays of calves produced by matings of presumed clean sires and dams. These errors in genotype predictions cannot be explained. It must be concluded that 22 percent of this group of 36 known dwarf carriers did not have the vertebral abnormalities thought to be characteristic of dwarf carriers. These results support the statement by High *et al.* (1958) that the X-ray method is not highly accurate in identifying individual animals with respect to their genotype for dwarfism.

It is interesting to note the differences in distribution within the B classification between carriers proven by progeny test and carriers from a single dwarf parent. Of the nine B X-rays of progeny tested calves, 56 percent were B_5 or worse, while only about 10 percent were B_1. Of the 19 B X-rays of calves from one dwarf parent, 10 percent were B_5 or worse, 32 percent were B_1, and 79 percent were B_2 or B_1. These figures indicate that the carriers resulting from matings of phenotypically normal animals have more extreme vertebrae abnormalities than carriers that have one dwarf parent.

Table III also shows the X-ray classifications of a group of 49 phenotypic dwarfs, including calves from Project 670, Project 873, the Oklahoma State University purebred herd and three privately owned herds. Hereford, Angus and crossbred dwarfs are included in this group. Approximately 94 percent of these dwarfs had typical dwarf vertebrae (classified A), and the remaining six percent of the group had extremely abnormal vertebrae (classified B_8). This represents a six-percent error in classifying dwarfs by X-ray. However, since no normal calves have had typical dwarf X-rays, 100 percent of the animals classified A have been dwarfs. These results agree with the conclusion by High *et al.* (1958) that the X-ray method is highly accurate in identifying snorter dwarf calves. Normally, the dwarf calf is distinguishable phenotypically, but in some cases the identification is doubtful with very young calves, stillbirths and calves that die before being observed. The X-ray method would be useful for identifying dwarfs in these doubtful cases.

It is difficult to obtain a good estimate of the accuracy of the X-ray method in classifying calves that are free of dwarfism. The main problem lies in proving that the animals *are* free of the dwarf gene. A grade Hereford herd (Project 650) that has no dwarfism history and has produced no dwarfs from 43 matings to known carrier bulls was used in these X-ray studies. It is assumed that this herd is free of dwarfism; therefore, matings with non-carrier bulls should produce homozygous normal offspring.

In Table IV are seen the distributions of X-ray classifications of the calves in the Project 650 herd divided according to the dwarfism status of the sires. Nineteen bulls that were presumed to be free of dwarfism sired 317 calves, classified 74.4 percent C and 25.6 percent B on X-rays. Hazel (1957) estimated approximately 80 percent of 3000 pedigree clean animals were classified correctly. However, he also reported that this fraction varies a great deal depending on the genetic makeup of the line, and in some clean lines practically all calves classify as C, while in others as many as 50 percent classify as mild B. In Table IV, it is seen that 23 percent of the calves are classified B_1 or B_2, and only 2.6 percent are more abnormal than B_2. These data indicate that some factor other than the dwarf gene can cause mild vertebral abnormalities which are detected in lumbar radiographs.

The effect of the dwarf gene on calves in this same herd is seen in the offspring of the two known carrier bulls. Of 43 offspring, only 53.5 percent were classified C, and 46.5 percent were classified B. There is also some tendency toward the more extreme B classifications in this group. The X-ray classifications among the progeny of a bull that is considered to be a possible carrier from pedigree analysis are divided one third B and two thirds C. This gives no indication as to the genotype of the bull.

If the X-ray predictions were completely accurate and the numbers large enough, matings of heterozygous bulls to heterozygous cows should

TABLE IV

SUMMARY OF X-RAY CLASSIFICATIONS OF CALVES PRODUCED IN A HERD BELIEVED TO BE FREE OF THE DWARF GENE

No. Bulls	Dwarfism Status of Bulls	No. Calves	X-Ray Classification (Percent of Total)								
			C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
19	Presumed Clean	317	74.4	13.9	9.1	1.0	1.0	.3	.3	-	-
2	Known Carrier	43	53.5	11.6	23.3	4.7	2.3	2.3	-	2.3	-
1	Possible Carrier	18	66.7	16.7	16.7	-	-	-	-	-	-

produce offspring with C, B and A classifications in a 1:2:1 ratio. In Table V are seen the X-ray classifications of the progeny of six dwarf carrier bulls bred to carrier cows in the "tester" herd. Of 34 calves, 26.5 percent were predicted to be clean, 47 percent were predicted to be carriers, and 26.5 percent were classified as dwarfs by X-ray. This very closely approaches the expected distribution of 25:50:25, and the deviations give a chi-square value of .117 ($P > .90$). The accuracy of the X-ray predictions cannot be measured very precisely with data of this kind. The classification of some known carriers as C and some presumed clean animals as B has already been discussed. With this situation, the errors in predictions tend to cancel each other in a distribution such as is shown in Table V. Nevertheless, the fact that the distribution of X-ray classifications corresponds with the expected distribution of genotypes does furnish evidence of a close association between vertebrae abnormalities and the dwarf gene.

TABLE V

SUMMARY OF X-RAY CLASSIFICATIONS OF CALVES FROM HETEROZYGOUS X HETEROZYGOUS MATINGS

Bull No. & X-Ray	No. Calves	X-Ray Classification (Percent of Total)									
		C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	A
5-23 (C)	6	66.7	-	-	-	-	-	-	-	-	33.3
5-26 (B_4)	6	16.7	16.7	33.3	-	-	16.7	-	-	-	16.7
I-14 (B_5)	2	-	50.0	-	-	-	-	-	-	-	50.0
I-17 (B_7)	7	-	-	28.6	-	28.6	-	-	-	-	42.8
535 (B_8)	6	33.3	-	-	-	16.7	-	33.3	-	-	16.7
T76 (B_8)	7	28.6	28.6	14.3	-	14.3	-	-	-	-	14.3
ALL	34	26.5	11.8	14.7	-	11.8	2.9	5.9	-	-	26.5
SUMMARY		26.5				47					26.5

During the four years in which calves from the carrier herd (Project 873) were X-rayed, 53 bulls that had been X-rayed as calves were progeny tested. The distributions of X-ray classifications of the offspring of these X-rayed bulls mated to dwarf carrier cows are seen in Table VI. The 16 Hereford bulls predicted carrier on X-ray sired 69 calves, of which, 23 percent were classified C, 67 percent were classified B, and 10 percent were classified A. If the X-ray predictions on all bulls and all calves were correct, the expected distribution of classifications would be 25:50:25. The number of C's (predicted clean) is very near the expected, but the number of dwarfs produced is far below the expected 25 percent.

The seven dwarfs that were produced proved five of the 16 bulls to be carriers. Of the remaining 11 B Hereford bulls, only two have sired six calves each, giving a probability of .178 that they could be carriers. Two bulls have sired only five calves each, giving a probability of .237 that they could be carriers. Since the remaining seven bulls classified as B sired less than five calves each, the probability that they could be carriers is still fairly high ($P > .237$). It appears that at least part of the deviation seen in the distribution of X-rays is caused by clean bulls in the predicted carrier group. However, the progeny tests do not include enough offspring to indicate which individual bulls are clean.

Seven Angus bulls that were predicted carriers by X-ray sired 39 calves, classified 28 percent C and 72 percent B. The 28 percent predicted clean deviates only slightly from the 25 percent expected. No dwarfs were produced, while 25 percent were expected, and no X-rays were more abnormal than B_5. It seems likely that some of the B Angus bulls

TABLE VI

SUMMARY OF X-RAY CLASSIFICATIONS OF ALL CALVES FROM MATINGS OF HETEROZYGOUS COWS TO X-RAYED BULLS

Breed	X-Ray Class	No. Bulls	No. Calves	X-Ray Classification (Percent of Total)									
				C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	A
Hereford	B	16[1]	69	23.2	15.9	18.8	4.3	13.0	7.2	5.8	1.4	-	10.1
Angus	B	7	39	28.2	20.5	20.5	15.4	5.1	10.3	-	-	-	-
Combined	B	23	108	25.0	17.6	19.4	8.3	10.2	8.3	3.7	.9	-	6.5
Hereford	C	21[2]	130	42.3	20.8	17.7	6.9	3.1	3.1	1.5	1.5	1.5	1.5[3]
Angus	C	9	56	58.9	17.9	14.3	5.4	3.6	-	-	-	-	-
Combined	c	30	186	47.3	19.9	16.7	6.5	3.2	2.2	1.1	1.1	1.1	1.1

[1] Five have proven to be carriers by siring dwarfs.
[2] Includes one known heterozygous bull (OK 5-23).
[3] Two dwarfs sired by OK 5-23.

are clean, since two bulls, 115 and H175, have sired seven phenotypically normal calves each, and one bull, 185, has sired eight normal calves from matings to carrier cows. (See Table VIII for probabilities that these bulls could be carriers.) If these three bulls are clean, only about 10 percent dwarfs would be expected, since the remaining four bulls sired a total of only 17 calves.

Combining the Hereford and Angus bulls that were predicted carriers, the distribution of offspring X-ray classifications is 25 percent C, 68.5 percent B and 6.5 percent A. If predictions on all bulls were correct, the expected distribution of offspring is 25 percent clean, 50 percent carrier and 25 percent dwarf. Errors in classifying the bulls would have a greater effect on the distribution than errors in classifying the offspring. The deviations from the expected numbers have a probability of less than .005, as tested by chi-square. The low percentage of dwarfs from predicted carrier X known carrier matings might be caused by reasons other than errors in predicting the sires. There is a possibility that undetected abortions or early stage resorptions of dwarf fetuses could be responsible for part of this discrepancy. At the Fort Reno Station, several dwarfs have been stillborn, and some have died shortly after birth. During 1956 and 1957, of 76 carrier cows that were settled from matings to predicted carrier bulls, only 90 percent produced calves. Of the cows settled from matings to predicted clean bulls, 100 percent produced calves. However, no differences were observed in 1958 and 1959. Foetal death of dwarfs is at least feasible and could account for low numbers in this class.

Table VI also shows the distribution of X-rays of calves produced from matings of predicted clean bulls to carrier cows. Of 21 Hereford bulls classified C, one has been proven a carrier by progeny test. The X-rays of 130 calves sired by these 21 C bulls are distributed 42.3 percent C, 56.1 percent B and 1.5 percent A. The expected distribution from clean X carrier matings is 50 percent clean and 50 percent carrier. Considering that 22 percent of known carriers (Table III) have been classified as C, it seems that the deviation in this distribution might easily be due in part to the presence of more carrier bulls among the remaining 20 C bulls of unknown genotype. Also, some errors in predicting genotypes of offspring may have occurred, but these would have some tendency to offset each other as far as the ratio between B and C types is concerned.

The X-rays of 56 offspring from nine predicted clean Angus bulls mated to carrier cows are distributed 59 percent C and 41 percent B (Table VI). None of the Angus bulls have proven to be carriers in progeny tests. The probability of this deviation from the expected 1:1 ratio is less than .25, as determined by chi-square.

Combining Hereford and Angus bulls of C classifications, the 186 offspring are classified 47.3 percent C, 51.6 percent B and 1.1 percent A. Omitting the progeny of the one proven carrier Hereford bull, the remaining calves are classified approximately 47 percent C and 53 percent B. The deviation from the expected 1:1 ratio gives a chi-square value of .80 ($P > .25$), indicating that this distribution would be expected if the other 20 C bulls were dwarf free.

The main reason for maintaining a herd of dwarf carrier cows at Fort Reno is to provide a progeny test for bulls predicted as to dwarfism genotype by various methods. Of the 53 X-rayed bulls used in this "tester" herd, six have proven to be carriers (See Table V).

These are also included in the known carrier group in Table III. Table VII gives the X-ray classifications of 28 bulls that have sired no dwarfs from six or more matings in the carrier herd. The bulls are grouped according to level of probability attained in the progeny tests. The probability levels are taken from the binomial distribution of offspring from carrier X carrier matings (3/4 normals plus 1/4 dwarfs), based on the assumption that the bull is a carrier. The expansion of the binomial $(3/4 + 1/4)^n$, where n is the number of offspring, gives the term, $(3/4)^n$, for the probability of getting all normal calves. If n normal calves result from the mating of a bull of unknown genotype to heterozygous cows, the probability that the bull is heterozygous is $(3/4)^n$.

TABLE VII

SUMMARY OF X-RAY CLASSIFICATIONS OF BULLS THAT HAVE BEEN PROGENY TESTED BY MATINGS WITH HETEROZYGOUS COWS

Level of Probability[1]	No. Bulls	No. of Bulls in Each X-Ray Class									
		C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	A
.07-.10	9	8	-	-	-	1	-	-	-	-	-
.10-.13	9	7	1	-	-	-	-	-	-	1	-
.13-.18	10	6	2	1	-	-	-	-	-	1	-

[1] Probability of a heterozygous animal remaining undetected with the number of test matings made.

Of the nine bulls tested to a level that would by chance alone allow less than one out of ten carriers to remain undetected, eight were predicted clean (C), and one was predicted a carrier (B_4). The X-ray classifications of this group fit the theoretical distribution as closely as possible. Of the nine bulls tested to a level of probability between .10 and .13, seven were predicted clean, and two were predicted carriers; and of the 10 bulls tested to a level between .13 and .18, six were predicted clean, and four were predicted carriers.

Considering the meaning of the probability levels, it is possible that one carrier in the first group (P =.07-.10), one carrier in the second group (P =.10-.13) and two carriers in the third group (P = .13 -18) could be revealed by further testing. Theoretically, this would leave three errors in predictions out of 28 bulls classified by the X-ray method. However, one cannot assume that the carriers revealed by further matings would not include bulls classified C as well as bulls classified B. Without making assumptions, it can be concluded from the data shown in Table VII that out of 28 bulls indicated by progeny test to be clean ($P > .82$), 21 were classified C, and seven were classified B. These results suggest that the X-ray method is at least 75 percent accurate in distinguishing dwarf free animals.

Matings of non-carrier bulls to carrier cows should produce, on the average, 50 percent non-carrier calves and 50 percent carrier calves. In Table VIII are seen the X-ray classifications of offspring of 28 bulls, indicated by progeny tests to be clean, mated to dwarf carrier cows. The "level of testing" and X-ray classification for each bull is indicated. The highest probability that any individual bull in this group could be a carrier is approximately .18. Of 194 calves X-rayed, 42.3 percent were predicted clean, and 57.7 percent were predicted carriers. The deviation from the expected 50:50 distribution gives a chi-square value of 4.64 ($P < .05$), indicating that the distribution of X-ray classifications is probably different from the expected distribution of genotypes. However, no definite conclusion as to the accuracy of

TABLE VIII

X-RAY CLASSIFICATIONS OF THE CALVES OF PROGENY TESTED BULLS MATED TO HETEROZYGOUS COWS

Bull No.	Bull X-Ray	Prob. Level[1]	No. Calves X-Rayed	No. of Calves in Each X-Ray Class								
				C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
D247	-	.032	7	4	-	1	2	-	-	-	-	-
5-02	C	.056	10	5	-	3	1	1	-	-	-	-
445	C	.075	9	6	2	1	-	-	-	-	-	-
T627	C	.075	9	5	3	1	-	-	-	-	-	-
6-09	C	.10	7	2	-	2	1	-	-	2	-	-
6-05	C	.10	6	2	3	1	-	-	-	-	-	-
6-47	C	.10	8	3	4	-	-	1	-	-	-	-
456	C	.10	8	5	3	-	-	-	-	-	-	-
185	B_4	.10	8	3	-	4	-	-	1	-	-	-
175	C	.10	8	5	-	2	-	1	-	-	-	-
517	C	.133	7	4	2	1	-	-	-	-	-	-
T609	C	.133	7	1	-	1	2	2	-	-	1	-
T610	C	.133	7	1	3	2	1	-	-	-	-	-
T82	C	.133	7	2	2	2	-	-	-	-	1	-
115	B_1	.133	7	3	2	1	1	-	-	-	-	-
T72	C	.133	6	4	-	1	1	-	-	-	-	-
H175	B_8	.133	7	1	1	-	2	2	1	-	-	-
610	C	.133	7	4	1	1	1	-	-	-	-	-
226	C	.133	7	3	2	1	-	1	-	-	-	-
4-26	C	.178	6	2	-	-	2	-	2	-	-	-
I-55	C	.178	6	4	1	1	-	-	-	-	-	-
6-29	C	.178	4	3	1	-	-	-	-	-	-	-
5-33	C	.178	6	2	2	1	-	-	1	-	-	-
6-44	B_2	.178	6	2	1	2	-	1	-	-	-	-
6-11	B_2	.178	6	1	1	1	-	-	2	-	1	-
5-85	C	.178	6	-	1	1	1	-	1	-	-	2
104	C	.178	6	4	-	1	1	-	-	-	-	-
455	B_3	.178	6	1	1	1	3	-	-	-	-	-
Total			194	82	36	33	19	9	8	2	3	2
Summary (%)				42.3				57.7				

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[1] Probability that the bull could be a carrier based on number of normal progeny with no dwarfs.

predictions on the calves can be drawn from this distribution of X-rays because the bulls have not been tested to a level high enough to give much confidence that the group includes no carriers.

The X-ray classifications of the progeny of 19 presumed clean bulls are divided into sire groups in Table IX. If the mild abnormalities found in presumed dwarf free cattle are not inherited, the B X-rays should be randomly distributed among the sires. However, as seen in Table IX, some sire groups, such as RN, 1-03 and 2-42, have less than 15 percent B X-rays; while others, such as 3-11 and 5-85, have almost 50 percent B X-rays. Noting the large number of calves sired by each of these bulls, it is not likely that the differences in classifications of offspring could be due to sampling errors. These figures indicate that the mild abnormalities found in this presumed clean herd are controlled by hereditary factors other than the dwarf gene. This conclusion is supported by a general statement by Hazel (1957) that the fraction of clean animals classified correctly varies a great deal depending on the genetic makeup of the line.

In Table X are seen the X-ray classifications of calves produced over a five-year period in a purebred Hereford herd. Half of the cows are considered possible carriers from their pedigrees, and half are pedigree clean. All calves were sired by bulls believed to be dwarf free. Twenty-four pedigree clean cows produced 63 calves, 32 percent of which were classified B on X-ray. However, of the 21 B X-rays, 11, or 52 percent were produced by only three of the cows. Twenty-one possible carrier cows produced 64 calves, of which, 42 percent were classified B. In both groups, there is a tendency for repeatability of X-ray classifications on calves from the same cow. Of ten cows that produced five

TABLE IX

DISTRIBUTIONS OF X-RAYS AMONG THE PROGENY OF BULLS PRESUMED TO BE FREE OF THE DWARF GENE MATED TO COWS PRESUMED TO BE FREE OF THE DWARF GENE

Bull No.	No. Calves	X-Ray Classification (Percent of Total)								
		C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
3-11	29	58.6	31.0	10.3	-	-	-	-	-	-
RN	25	96.0	-	4.0	-	-	-	-	-	-
42	24	79.2	12.5	8.3	-	-	-	-	-	-
20	23	78.3	8.7	4.3	-	4.3	4.3	-	-	-
5-20	23	73.9	17.4	8.7	-	-	-	-	-	-
5-16	22	72.7	4.5	22.7	-	-	-	-	-	-
1-03	21	85.7	9.5	4.8	-	-	-	-	-	-
5-02	20	65.0	20.0	10.0	-	5.0	-	-	-	-
2-19	20	60.0	20.0	15.0	5.0	-	-	-	-	-
5-85	17	41.2	17.6	23.5	5.9	5.9	-	5.9	-	-
19	16	87.5	-	12.5	-	-	-	-	-	-
3-09	15	66.7	26.7	6.7	-	-	-	-	-	-
4-50	14	78.6	14.3	7.1	-	-	-	-	-	-
2-42	11	90.9	9.1	-	-	-	-	-	-	-
4-25	11	90.9	-	9.1	-	-	-	-	-	-
182	7	71.4	14.3	-	14.3	-	-	-	-	-
4-08	6	83.3	16.7	-	-	-	-	-	-	-
3-43	4	100.0	-	-	-	-	-	-	-	-
4-16	2	100.0	-	-	-	-	-	-	-	-

calves each; one cow had all calves classified C, two cows had all calves classified B, three cows had four C's and one B, one cow had four B's and one C, two cows had three B's and two C's, and two cows had three C's and two B's. If the classifications were random, fewer cows would have most of their offspring in one class. The data in Table X add to the evidence that some vertebral abnormalities are controlled by hereditary factors other than the dwarf gene.

TABLE X

SUMMARY OF X-RAYS OF CALVES PRODUCED BY PUREBRED HEREFORD COWS MATED TO PRESUMED CLEAN BULLS OVER A FIVE-YEAR PERIOD

Dwarfism Status	No. Calves	No. Calves in Each X-Ray Class								
		C	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
Possible Carrier	64	37	11	9	2	1	2	-	1	1
Summary (%)		58	42							
Pedigree Clean	63	42	9	8	3	1	-	-	-	-
Summary (%)		68	32							

Differences in the number of males and females within X-ray classes have been observed and are summarized in Table XI. The C classification includes 323 males and 420 females, while the B classification includes 371 males and 274 females. Under the hypothesis that males and females are equally susceptible to abnormalities of the vertebrae, these ratios have a probability of less than .005, as tested by chi-square. Abnormal X-rays were found among males more often than among females. Of 694 males X-rayed, 53.5 percent were classified B; whereas, of 694 females, only 39.5 percent were classified B.

TABLE XI

DISTRIBUTIONS OF SEXES WITHIN X-RAY CLASSIFICATIONS

Classification	Observed		Expected		Chi-square	Prob.
	Male	Female	Male	Female		
C	323	420	371.5	371.5	12.66	$P < .005$
B	371	274	322.5	322.5	14.59	$P < .005$
B_1	142	115	128.5	128.5	2.84	$P < .10$
B_{2-8}	229	159	194	194	12.63	$P < .005$

The B classifications were divided into two groups, B_1 and B_{2-8}, in an attempt to find where most of the sex differences lie. Of 274 females classified B, 42 percent were in the B_1 class, and 58 percent were in the more extreme B classes. Of 371 males classified B, 38.3 percent were in the B_1 class, and 61.7 percent were in the more extreme B classes. As seen in Table X, the deviation from a 1:1 ratio of males to females within the B_1 class has a probability near .10, and the deviation from a 1:1 ratio within the group comprised of classes B_2 through B_8 has a probability of less than .005 (tested by chi-square). These data indicate that not only are more males afflicted with vertebral abnormalities, but the abnormalities are more extreme in male than females.

The X-ray classifications were given a numerical value ($C = 1$, $B_1 = 2$, $B_2 = 3$, . . . $B_8 = 9$). Under this scoring system, 694 males had an average X-ray classification of 2.31, and 694 females had an average X-ray classification of 1.79. These data suggest that there is a factor associated with the male sex which augments the expression of vertebral abnormalities of genetic origin.

SUMMARY

For the past five years the X-ray method for detecting animals heterozygous for the snorter dwarf gene has been investigated. This method is based on vertebrae abnormalities as shown on lateral lumbar radiographs of young calves. This study includes radiographs of more than 1500 calves of Hereford and Angus breeding, representing three different beef cattle research projects located at the Fort Reno Agricultural Experiment Station.

Of 36 animals known to be heterozygous for the dwarf gene, 77.8 percent were classified as B (predicted to be heterozygous), and 22.2 percent were classified as C (predicted to be homozygous normal). Of 317 calves that are presumed to be free of the dwarf gene, 74.4 percent were classified as C (predicted to be homozygous normal), and 25.6 percent were classified as B (predicted to be heterozygous). Of 49 phenotypic dwarfs, 96 percent were classified as A (predicted to be dwarfs), and 6 percent were classified as B_8 (predicted to be heterozygous). These data provide the following estimates of accuracy for the X-ray method: (1) 78 percent accurate in identifying dwarf carrier animals; (2) 74 percent accurate in identifying dwarf free animals; (3) 96 percent accurate in identifying dwarfs.

Distributions of X-ray classifications of the offspring from carrier X carrier and presumed clean X carrier matings indicate a very close association between vertebrae abnormalities and the dwarf gene. These distributions do not refute the limits of accuracy stated above.

The abnormalities seen in radiographs of presumed dwarf free animals are, on the average, less severe than those thought to be caused by the snorter dwarf gene. The frequency of mild abnormalities varies between different lines of breeding and different sire groups. Twenty-five percent of the calves from a grade Hereford herd presumed to be dwarf free had abnormal X-rays, while 32 percent of the calves from a pedigree clean purebred Hereford herd had abnormal X-rays. These mild vertebrae abnormalities seem to be controlled by a hereditary factor other than the dwarf gene.

Sex differences were found within the X-ray classifications. More males had abnormal X-rays than females, and the abnormalities were more extreme in the males. Converting the X-ray classifications (excluding the A class) to numerical values, 694 males had an average abnormality score of 2.31, while 694 females averaged 1.79 (compared to a value of 1.0 for normal X-rays). These differences cannot be explained from the information provided by this study.

The X-ray method is considered to be highly accurate in identifying dwarf calves and might be of use when phenotypic identification is doubtful. This method is not highly accurate in distinguishing between carriers and non-carriers of the dwarf gene among normal appearing animals. However, the limits of accuracy are high enough that the method might have some value as an aid in screening animals prior to progeny testing them for dwarfism.

SELECTED BIBLIOGRAPHY

Arthaud, R. L., R. M. Koch and V. H. Arthaud. 1957. Anatomical measurements as related to the snorter dwarf gene in Hereford calves. J. Animal Sci. 16:1028 (abstract).

Baker, M. L., C. T. Blunn and M. Oloufa. 1950. Stumpy, a recessive achondroplasia in Shorthorn cattle. J. Heredity 41:243.

Baker, M. L., C. T. Blunn and M. Plum. 1951. Dwarfism in Aberdeen-Angus cattle. J. Heredity 42:141.

Bovard, K. P., L. N. Hazel and M. A. Emmerson. 1956. Effects of the snorter dwarf gene on the lumbar vertebrae and metacarpus in Hereford calves at birth. J. Animal Sci. 15:1213 (abstract).

Buchanan, M. L., F. M. Bolin, J. J. Burnham and D. F. Eveleth. 1956. Some skeletal changes associated with dwarfism in cattle. N. Dak. Agr. Exp. Sta. Bul. 403.

Carroll, F. D., P. W. Gregory and W. C. Rollins. 1951. Thyrotropic hormone deficiency in homozygous dwarf beef cattle. J. Animal Sci. 10:916.

Chambers, Doyle, T. J. Marlowe and J. A. Whatley, Jr. 1954a. A review of studies on dwarfism in beef cattle. Okla. Agr. Exp. Sta. Misc. Publ. MP-34:29.

Chambers, Doyle, J. A. Whatley, Jr. and D. F. Stephens. 1954b. The inheritance of dwarfism in a comprest Hereford herd. J. Animal Sci. 13:956 (abstract).

Cole, C. L. and L. A. Moore. 1942. Hydrocephalus, a lethal in cattle. J. Agr. Res. 65:483.

Craft, W. A. and H. W. Orr. 1924. Thyroid influence in cattle. J. Heredity 15:255.

Crew, F. A. E. 1923. The significance of an achondroplasia-like condition met with in cattle. Proc. Royal Soc. of London. Series B 95:228.

Dollahon, J. C., M. Koger, J. F. Hentges and A. C. Warnick. 1957. The expression of various forms of dwarfism in certain crosses and heterogeneous genetic backgrounds in beef cattle. J. Animal Sci. 16:1029 (abstract).

Downs, Jr., W. G., B. Bryant, R. Kinsolving, R. Hamilton and J. M. Thompson. 1959. Achondroplastic dwarfs in cattle. J. Tenn. Acad. Sci. 34:52.

Emmerson, M. A. and L. N. Hazel. 1956. Radiographic demonstration of dwarf gene-carrier beef animals. J. Amer. Vet. Med. Assn. 128:381.

Eveleth, D. F., F. M. Bolin, and M. L. Buchanan. 1956. Abnormal shape of the heart of dwarf cattle. Vet. Med. 51:495.

Forbes, R. C. 1946. How about comprests? Compacts? Breeders Gazette 111 (10):12.

Fransen, J. M. 1955. The morphological and physiological aspects of dwarfism in beef cattle. Ph.D. Thesis. Purdue Univ.

Fransen, J. M. and F. N. Andrews. 1954. The physiology of dwarfism in beef cattle. J. Animal Sci. 13:1020.

Gregory, P. W. 1955. The genetic relationships of phenotypically different bovine dwarfs. J. Animal Sci. 14:1182 (abstract).

Gregory, P. W. 1956. Phenotypic forms and genetic relationships of the bovine dwarf complex. J. Animal Sci. 15:1207 (abstract).

Gregory, P. W. and B. B. Brown. 1952. A profilometer for studying head form of the bovine. J. Animal Sci. 11:700.

Gregory, P. W. and F. D. Carroll. 1956. Evidence for the same dwarf gene in Hereford, Aberdeen-Angus and certain other breeds of cattle. J. Heredity 47:106.

Gregory, P. W., L. M. Julian, and W. S. Tyler. 1957. The validity of dwarf carrier cows as testers for the major dwarf conditioning gene. J. Animal Sci. 16:1028 (abstract).

Gregory, P. W., W. C. Rollins, and F. D. Carroll. 1952. Heterozygous expression of the dwarf gene in beef cattle. The Southwest. Vet. 5:345.

Gregory, P. W., W. C. Rollins, P. S. Pattengale, and F. D. Carroll. 1951. A phenotypic expression of homozygous dwarfism in beef cattle. J. Animal Sci. 10:922.

Gregory, P. W., C. B. Roubicek, F. D. Carroll, P. O. Stratton and N. W. Hilston. 1953. Inheritance of bovine dwarfism and the detection of heterozygotes. Hilgardia 22:407.

Hazel, L. N. 1957. Summary of X-ray research with dwarfism. Proc. 1957 Tech. Committee Meeting NC-1. pp. 66.

Hazel, L. N., M. A. Emmerson and K. P. Bovard. 1956. Radiographic examinations of lumbar vertebrae as a method of detecting carriers of the snorter dwarf gene. J. Animal Sci. 15:1213 (abstract).

High, J. W. Jr., H. J. Smith, C. S. Hobbs and C. M. Kincaid. 1958. Evaluation of the X-ray method of detecting animals heterozygous for the snorter dwarf gene. J. Animal Sci. 17:1140 (abstract).

Hughes, H. V. and J. W. Dransfield. 1953. <u>McFadyeans Osteology and Arthrology of the Domesticated Animals</u>. Bailliere, Tindall and Cox, London.

Hutt, F. B. 1934. Inherited lethal characters in domestic animals. Cornell Vet. 24:1.

Johansson, I. 1953. A new type of achondroplasia in cattle. Hereditas 39:75.

Johnson, L. E., G. S. Harshfield and W. McCone. 1950. Dwarfism, an hereditary defect in beef cattle. J. Heredity 41:177.

Julian, L. M., W. S. Tyler and P. W. Gregory. 1956. Systematic studies on the anatomical expression of bovine dwarfism. J. Animal Sci. 15:1208 (abstract).

Koger, M., J. C. Dollahon, A. C. Warnick, W. G. Kirk, J. F. Hentges and A. Z. Palmer. 1955. Forms of dwarfism in English and Brahman breeds of beef cattle. J. Animal Sci. 14:1186 (abstract).

Lindley, C. E. 1951. Observations on midgets in beef cattle. J. Heredity 42:273.

Lush, J. L. 1930. "Duck-legged" cattle on Texas ranches. J. Heredity 21:85.

Lush, J. L. and L. N. Hazel. 1952. Inheritance of dwarfism. The Amer. Hereford J. 42:32.

Lush, J. L. and L. N. Hazel. 1955. Dwarfism in beef cattle. Hereford Quarterly vol. 1-4:4.

McLeroy, G. B., E. G. Moody and W. A. Smith. 1954. A report of some experiments with a Hereford dwarf. Agr. Dept. Pub. Arizona State College, Tempe.

Mead, S. W., P. W. Gregory and W. M. Regan. 1942. Proportionate dwarfism in Jersey cows. J. Heredity 33:411.

Mead, S. W., P. W. Gregory and W. M. Regan. 1946. A recurrent mutation of dominant achondroplasia in cattle. J. Heredity 37:183.

Pahnish, O. F., E. B. Stanley and C. E. Safley. 1952. A study of homozygous dwarfism in beef cattle. Proc. West. Sect. Amer. Soc. Animal Prod. III:IX.

Pahnish, O. F., E. B. Stanley and C. E. Safley. 1955a. The inheritance of a dwarf anomaly in beef cattle. J. Animal Sci. 14:200.

Pahnish, O. F., E. B. Stanley and C. E. Safley. 1955b. The breeding history of an experimental herd of dwarf beef cattle. J. Animal Sci. 14:1025.

Pahnish, O. F., E. B. Stanley, C. E. Safley and C. B. Roubicek. 1955c. Dwarfism in beef cattle. Arizona Agr. Exp. Sta. Bul. 268.

Schoonover, C. O. and P. O. Stratton. 1954. A study of recessive dwarfism in Hereford females. Proc. West. Sect. Amer. Soc. Animal Prod. V:233.

Schoonover, C. O. and P. O. Stratton. 1958. The relationship of head form to economic factors in Hereford heifers. Proc. West. Sect. Amer. Soc. Animal Prod. IX:XLVI.

Snedecor, G. W. 1956. Statistical Methods. 5th ed. The Iowa State State College Press, Ames, Iowa.

Stonaker, H. H. 1954. Dwarfism in beef cattle. Proc. West. Sect. Amer. Soc. Animal Prod. V:289.

Stonaker, H. H., M. H. Hazaleus and S. S. Wheeler. 1952. Feedlot and carcass characteristics of individually fed comprest and conventional type Hereford steers. J. Animal Sci. 11:17.

Stonaker, H. H. and R. C. Tom. 1944. "Compact" Shorthorns. J. Heredity 35:247.

Sisson, S. and J. D. Grossman. 1953. The Anatomy of Domestic Animals. 4th ed. rev. W. B. Saunders Company, Philadephia and London.

Turman, E. J., R. D. Humphrey, Doyle Chambers and Dwight Stephens. 1957. Radiographs of the lumbar vertebrae of beef calves and their association with the snorter dwarf gene. Okla. Agr. Exp. Sta. Misc. Pub. MP-48:33.

Turman, E. J., B. J. Watkins, Doyle Chambers, Dwight Stephens and R. D. Humphrey. 1958. X-rays of lumbar vertebrae as a method for detecting carriers of dwarfism. Okla. Agr. Exp. Sta. Misc. Pub. MP-51:9.

Tyler, W. S., T. M. Julian and P. W. Gregory. 1956. Identification of the process responsible for the short-headed Hereford dwarf based on anatomical studies. J. Animal Sci. 15:1207 (abstract).

Warwick, E. J. 1958. Fifty years of progress in breeding beef cattle. J. Animal Sci. 17:922

Wriedt, C. 1930. Heredity in Livestock. Macmillan, London.

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