150

THE AGE AND MANNER OF CLOSURE OF VARIOUS EPIPHYSES AND OTHER CENTERS OF OSSIFICATION IN THE FRONT LIMB OF THE DOMESTIC HORSE (EQUUS CABALLUS)

by

Victor Shank Myers, Jr.

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Major Subject: Veterinary Medicine and Surgery

Iowa State University
Of Science and Technology
Ames, Iowa

1963

TABLE OF CONTENTS

INTRODUCTION

Abnormalities of the locomotor system are probably the most important single group of disorders to affect the equine species. Lameness is often the difference between a valuable and a worthless horse. Veterinarians are constantly being asked to treat lame horses. The first and often the most important step in treating lameness is the establishment of an accurate diagnosis. It is in this field of diagnosis of lameness that radiology has become so useful.

The development and improvement of radiology and the diagnostic radiograph have been followed by an increased demand for radiographic service. Portable x-ray machines have placed this important diagnostic tool in the hands of many veterinarians. The increased demand and the increased availability of the equipment have resulted in a previously infrequent procedure becoming almost routine.

After satisfactory radiographs are taken their value is entirely dependent upon the ability of the practitioner to properly interpret the information on the film. He must be able to differentiate between normal epiphyseal lines and fractures. He should know the normal ages for epiphyseal closure in order to recognize incomplete or late epiphyseal closures.

It becomes apparent that knowledge of the normal growth and development of bone not only aids in the diagnosis of lamenesses, but provides information to help guide the nutrition, training and use of these horses. If it is possible to make a correlation between the age of the animal and the time of epiphyseal closure, it should be possible to more logically control the use and training of horses.

It is evident, then, that the full potential of a good radiographic examination is not used unless the examiner has a knowledge of the developmental changes expected between birth and maturity.

Since no English work on radiographic epiphyseal closure times is available, it was concluded that a study such as this would be beneficial to both the equine practitioner and the research worker interested in bone growth and development. With the possible exception of a recent Russian study, all of the radiographic studies of epiphyseal closure in the equine species were made using radiographs of different horses of different ages and did not follow one horse through its postnatal development. These workers, thus, did not take full advantage of the radiographic method of studying bone development.

It was therefore proposed that two animals, as closely related as possible, would be kept under carefully controlled conditions to provide a uniform series of radiographs. These findings should provide a basis for diagnostic use as well as for subsequent research.

REVIEW OF THE LITERATURE

Although no attempt was made to conduct a complete review of the literature on epiphyseal closure times in all animals, the literature concerning some animals and some of the more recent human literature was reviewed.

In man, Pyle was found to be co-author of several atlases on bone development (40,20,27,39). Many recent studies of epiphyseal closure in the dog were found (24,25,54,55,23,49, 47,2,36,6). The monkey was studied by several workers including (63,65,34). Dawson (10,11) did the early work on the rat skeleton, while Walker and Wirtschafter (64) wrote a laboratory atlas on the development of the rat skeleton. Other animals were studied in relationship to their epiphyseal closure times (30,67,7,8,53,29,13).

Pryor (37,38) wrote that the bones of the human female developed more rapidly than those of the human male. As the children became older these differences became more marked. Stevenson (57) and Todd and Todd (60) did not confirm these results, but since then these findings were supported in man (33,17,18,26,19,20). They were also supported by people working on other species (34,63,56). In the dog Hare (25) found no sex influence, but he did find that there were differences between breeds. Raker,[1] Mackay-Smith,[2] and Buchanan[3] stated

[1]Raker, C. W. Philadelphia, Pa. Breed differences in maturity. Private communication. 1963.

[2]Mackay-Smith, M. P. Philadelphia, Pa. Breed differences in maturity. Private communication. 1963.

[3]Buchanan, J. H. Ames, Iowa. Breed differences in maturity. Private communication. 1963.

that the Arabian breed of horses matured relatively slowly when compared to other equine breeds. Raker also believed that the Standardbred horse matured more slowly than the Thoroughbred.

The following discussion of the formation and growth of bones was taken from these textbooks (22,62,5,35). Two types of bone were described. Intramembranous bones formed in fibrous or membranous areas did not have cartilage anlages. Endochondral bones were formed in areas where cartilage anlages had already been formed. It must be kept in mind, however, that all bone laid down by the periosteum and endosteum was actually formed by intramembranous ossification. Bone growth at epiphyseal lines was described as being endochondral in type.

All the bones of the forelimb of the horse were found to be of the endochondral type. A cartilaginous model of the limb bones developed early in the gestation period from embryonal mesenchymal cells. A mass of mesenchymal cells formed in the area and these cells became differentiated into chondroblasts. The chondroblasts then began to lay down cartilage. Surrounding this cartilage, a perichondrium became differentiated from the mesenchymal cells in that area.

The work of Ewart (15,16), Rosenberg (43), and Saarni (46) showed that cartilaginous anlages of the limb bones of the horse appeared during the first month of fetal life.

These cartilaginous anlages grew in both length and width by interstitial growth of the chondrocytes. Interstitial growth was described as growth from within by division and enlargement of the individual cartilage cells. Cartilage was also described as having appositional growth or the addition of new cartilage layers on the outside of the models. The inner layer of the perichondrium formed this new cartilage on the outside of the old.

The first center of ossification in the equine forelimb appeared during the second month of fetal life (Schmidt, 48; Saarni, 46; and Ewart, 15). The process began with the swelling and maturation of the cartilage cells in the area. The matrix around these cells gradually became thinner and calcified. After these chondrocytes became surrounded by a calcified matrix, they died. Following the death of these cells there was erosion and dissolution of the calcified matrix and the dead cells, leaving hollow spaces in the area. During this same period there was an increase in the blood supply to the perichondrium. This increased vascularity in some way affected the inner layer of the perichondrium, so that osteoblasts were formed instead of chondroblasts. This influence of cell environment on osteogenesis was emphasized by Bassett (3). According to Ham and Leeson (22), a center of ossification was formed when osteoblasts and capillaries had completed their invasion into the area of dead cartilage cells. Patten (35) emphasized that cartilage was not converted to bone, but rather cartilage was destroyed and bone then formed in the same area. There was no transition of cartilage to bone, but rather a replacement of destroyed cartilage with bone.

It was found that all the diaphyseal centers of ossification were present in the equine forelimb before any of the secondary centers of ossification appeared. Diaphyseal ossification began with the scapula and seemed to proceed in an orderly manner down the leg, except that the ossification center of the third phalanx appeared before that of the second phalanx. Schmidt (48) reported that the diaphyseal center of ossification of the scapula appeared toward the end of the second month of fetal life. Saarni (46) reported that all the diaphyseal centers were present in an equine fetus about 130 days after conception. Other works consulted were Küpfer (31), Ewart (15), and Tohara (61). Stoss (58) gave age ranges for equine fetuses of varying crown rump lengths. His work was consulted when crown rump lengths were given without ages.

Although bone did not grow by interstitial growth, due to its solid matrix, the osteogenic cells in the cambium layer of the periosteum did cause the diaphyses to grow in width by appositional growth. Appositional growth occurred when new bone was laid down on the outside of bone already present.

The shafts of the long bones in the young were continually undergoing changes according to Enlow (14). The endosteum and periosteum continually laid down intramembranous bone and resorbed bone from the diaphyseal shaft during early life.

Küpfer (31) stated that the first secondary center of ossification to appear in the equine fetus was the coracoid process of the scapula. According to Bloom and Bloom (4, pp. 508-509), the secondary or epiphyseal centers of ossification ossified in a different manner from the diaphyseal centers.

> Here the large mass of uncalcified cartilage is invaded centripetally by several thick cords of vascular mesenchyme. When the mesenchyme reaches the center, calcification starts in the surrounding cartilage matrix. Then erosion of this calcified cartilage by vascular mesenchyme begins and typical intracartilaginous ossification proceeds centrifugally, with the result that a progressively larger cavity filled with bone marrow and small amounts of spongy bone develops in the secondary center of ossification. This process continues until only a thin rim of cartilage is left at the articular surface and along the epiphyseal line. The latter is removed when the epiphyseal and diaphyseal cavities fuse when growth of the bone ceases.

Küpfer (31) listed the order of appearance of the secondary centers of ossification of the equine forelimb as follows: coracoid process, distal radial epiphysis, distal epiphysis of the third metacarpal bone, distal epiphysis of the humerus, distal epiphysis of the first phalanx, proximal epiphysis of the first phalanx, proximal epiphysis of the radius, proximal epiphysis of the humerus, epiphysis of the major tuberosity of the humerus, epiphysis of the medial epicondyle of the humerus, proximal epiphysis of the second phalanx, epiphysis of the lateral epicondyle of the humerus, proximal epiphysis of the ulna, and distal epiphysis of the ulna. Küpfer stated that the coracoid process had a center of ossification in a 51 cm. fetus between 23 and 28 weeks after conception. Küpfer did not find the ulnar epiphyses calcified until after birth, but Tohara (61) stated that if the olecranon process was not ossified at birth it was a sign of poor fetal development. Küpfer saw a second ossification nucleus in the skeletal zone of the scapula, which appeared just before birth between the coracoid process and the distal end of the scapula. Schmidt (48) mentioned this nucleus also.

It was stated that longitudinal growth of long bones occurred at the epiphyseal cartilages (22,62,5). The cartilage on the epiphyseal side of the line grew by means of interstitial growth, and continually pushed the epiphysis away from the diaphysis. On the diaphyseal side, there was continual replacement of the destroyed cartilage with spongy bone.

For descriptive purposes, Ham and Leeson (22) divided the epiphyseal line into four zones. Beginning on the epiphyseal side a layer of resting or dormant cartilage was found. This layer attached the epiphyseal line of cartilage to the bony epiphysis. The next zone contained active growing chondrocytes, and mitotic figures were often seen in this zone. These cells were arranged in columns stacked longitudinally. The third zone was made up of more mature cartilage cells still in the same longitudinal columns. These were the cells from zone two after the epiphysis had been pushed further away from them by means of interstitial growth of the cartilage. The cells in zone three closest to the diaphysis were the most mature. The fourth and last zone was made up mostly of dead chondrocytes surrounded by a calcified matrix. This layer of cells connected the epiphyseal plate to the diaphysis. These were not four completely isolated layers, as they all ran together and one could not determine exactly where one zone ended and the other began. Under the fourth zone of the epiphyseal line osteogenesis was taking place at the same speed as interstitial growth took place in zones two and three. This meant that in the young animal in which the long bones were growing in length, two processes were always going on at the same rate. One was the interstitial growth of cartilage in zones two and three. The other was the calcification of the cartilage matrix, the death of the chondrocytes, and the replacement of this dead cartilage by spongy bone. The part of the diaphysis adjoining zone four of the epiphyseal cartilage was called the metaphysis and it was made up of newly formed spongy bone. Submetaphyseal bone was continually undergoing resorption, replacement, and remodeling (Ingalls, 28). The epiphysis grew only by appositional growth which took place on all sides of the epiphysis, except along the epiphyseal cartilage side, according to Siegling (50).

Growth of the long bones stopped when the cartilage cells in zone two ceased to divide. When this happened the epiphyseal line ossified from the diaphyseal side and no further growth in length occurred at that particular epiphyseal line. As soon as any part of the cartilage zone was ossified, the bone could no longer grow in length at that epiphyseal line.

In reviewing the English literature on radiographic epiphyseal closure times in the equine, no original work was found. Adams (1) in his recent book on equine lamenesses did not mention epiphyseal closure times. Several men prominent in veterinary anatomy, veterinary radiology, and equine medicine and surgery were consulted (Raker,[1] Manning,[2] Riley,[3] Carlson,[4] Hare,[5] Smith,[6] Mackay-Smith,[7] Banks,[8]

---

[1]Raker, C. W. Philadelphia, Pa. Epiphyseal closure times. Private communication. 1963.

[2]Manning, J. P. Urbana, Ill. Epiphyseal closure times. Private communication. 1963.

[3]Riley, W. F. East Lansing, Mich. Epiphyseal closure times. Private communication. 1963.

[4]Carlson, W. D. Fort Collins, Colo. Epiphyseal closure times. Private communication. 1963.

[5]Hare, W. C. D. Philadelphia, Pa. Epiphyseal closure times. Private communication. 1963.

[6]Smith, R. N. Bristol, England. Epiphyseal closure times. Private communication. 1963.

[7]Mackay-Smith, M. P. Philadelphia, Pa. Epiphyseal closure times. Private communication. 1963.

[8]Banks, W. C. College Station, Texas. Epiphyseal closure times. Private communication. 1963.

Worthman,[1] Morgan,[2] Wheat,[3]) and none of these men knew of any English work on the subject. Since the aforementioned correspondences, Equine Medicine and Surgery (42) was published. Rooney (42) in this book quoted the chart listed in the German embryology book by Zietschmann and Krölling (66), on ages of epiphyseal closure in the horse. Actually, Zietschmann and Krölling derived their data from Lesbre (32), who published his works in 1897. Thus the most recent English reference on epiphyseal closure in the horse dated back to the end of the 19th century. Sisson and Grossman (52) gave closure times for some of the epiphyseal lines in the horse, but these were the same ones that Sisson (51) gave in 1910.

Lesbre (32) wrote on the sequence of skeletal ossification in domestic mammals. The horse was included in this study. For a summary of Lesbre's work, see Table 1 following the Discussion Section. Lesbre stated that he saw a definite distal epiphyseal line for the second phalanx after birth. This was an anatomical study of epiphyseal closure times.

In 1950 Tohara (61) published a radiographic study on equine bone development. In the English summary, Tohara

[1]Worthman, R. P. Pullman, Wash. Epiphyseal closure times. Private communication. 1963.

[2]Morgan, J. P. Fort Collins, Colo. Epiphseal closure times. Private communication. 1963.

[3]Wheat, J. D. Davis, Calif. Epiphyseal closure times. Private communication. 1963.

stated that the proximal end of the second phalanx fused in the 7th to 8th months. The distal end of the first phalanx was fused at birth, while the proximal epiphyseal line closed in the 9th to 10th months after birth. The distal end of the third metacarpal bone fused to the diaphysis in the 17th to 18th months. Tohara found no evidence of a proximal epiphysis of the third phalanx, a distal epiphysis of the second phalanx, or a proximal epiphyses of the metacarpal bones during the gestation period. These centers were described by Lesbre (32), Retterer (41), and Ewart (15), but were not seen by Küpfer (31) in the horse. According to Ellenberger and Baum (12), Küpfer (31) saw signs of a beginning proximal epiphysis of the third metacarpal bone in a 74 cm. esel (ass) fetus about fifty weeks after conception. Küpfer (31) did not say he saw a definite ununited epiphysis, but only that signs of the epiphysis were present in one esel fetus. Struthers (59) did not find an epiphysis for either the distal end of the second phalanx or the proximal end of the third, but he did think that they were probably present in younger fetuses. The age of the fetus Struthers described was said to be one month prior to delivery. Saarni (46) said the proximal epiphyses of the metacarpal bones were not ossified in an 89 cm. fetus, while they were already fused to the diaphysis in a 95 cm. fetus. He did not actually see an ununited epiphysis, however, Saarni (46) also described a distal epiphysis of the second phalanx.

In 1960 Schmidt (48) wrote on radiographic epiphyseal closure times in the equine limbs. According to Schmidt, the epiphyseal closure time of the proximal ends of the first and second phalanges and the distal end of the third metacarpal bone was six months of age. The other centers below the carpus were closed before birth, Schmidt said. The distal radial and ulnar epiphyses fused together before four months and these two then fused to the radial diaphysis by three years of age, Schmidt stated. The exact time of closure for the proximal epiphysis of the radius was not given, but it was joined in a year old horse. The exact closure times for the olecranon, proximal epiphysis of the humerus, the major tuberosity of the humerus, and the tuber scapulae were not determined. The tuber scapulae was united to the scapula by 18 months of age. The distal epiphysis of the humerus and the epiphysis of the medial epicondyle were fused in a year old horse, Schmidt stated.

Rozhdestvenskaya (45,44) published two papers in 1960 on the bone formation of foals during the first year of life. A German abstract of one of these articles gave no epiphyseal closure times, however.

Rooney (42), Zietschmann and Krölling (66), Lesbre (32), Sisson and Grossman (52), Küpfer (31), Tohara (61), and Schmidt (48) all gave epiphyseal closure times for some of the bones of the front limbs of the horse. None of these references, however, followed a single animal from birth to maturity as was done in this study.

METHODS AND MATERIALS

Two Arabian mares were chosen in January of 1960 to begin this study of bone development in the horse. They were very closely related and were bred to the same stallion. (See Charts 1 and 2 for pedigrees of the two experimental horses). Radiographs of both the mares and the stallion showed no signs of hereditary bone defects. These horses showed good bone development.

The mares were put in an isolation barn at Iowa State University approximately six weeks before they were due to foal. They were observed every 15 minutes, beginning two weeks before they were due to foal. This observation continued until both mares had foaled without complications. Neither of the mares had retained fetal membranes. A motion picture was taken of the colt's birth on April 21, 1960. The filly was born on May 4, 1960. No signs of infection were seen in either the mares or the foals. Both mares delivered healthy foals the next year.

The foals were kept in isolation after birth and were in contact with no horses except their dams. They were not ridden, but did receive controlled exercise in a special exercise yard under the supervision of their attendants. Both received yearly injections of equine encephalomyelitis vaccine and tetanus toxoid. They were treated for internal parasites eight time during the first three years of life. It was thought that their

Skowronek

Raffles

Skowronek

Rifala

Rissla

Azraff

Landsknecht

Azja IV

Asra

Filly
Comar Rafleygaz
Foaled 5-4-60

Mirage

IBN Mirage

Kareyma

Rafleyga

Raffles

Rafleyma

Raffles

Rafeyma

Kareyma

Chart 1. Pedigree of filly

Colt
Comar Barrymore
Foaled 4-21-60

- Azraff
  - Raffles
    - Skowronek
    - Rifala
      - Skowronek
      - Rissla
  - Azja IV
    - Landsknecht
    - Asra
- Bint Bint Kareyma
  - IBN Mirage
    - Mirage
    - Kareyma
  - Rafeyma
    - Raffles
    - Kareyma

Chart 2. Pedigree of colt

dams inocculated them with intestinal parasites.

As soon as the foals began to eat they received a 13.1 per cent digestable protein grain mixture to which was added a vitamin mixture (Clovite[1]) at the rate of one tablespoon per gallon of feed. A trace mineralized salt was also provided for the foals, and good alfalfa hay was available free choice. Both foals were weaned on November 4, 1960, at which time their grain ration was improved to a 13.2 per cent digestable protein mixture. The alfalfa hay as well as the vitamin and trace mineral supplements were continued. In the summer of 1962 the feed was reduced for both animals when it was thought that they were overweight. Both animals were in good flesh on their respective third birthdays.

Records were kept for each horse beginning with their births. These record all physical changes and treatments as well as weekly weights. (See Charts 3 and 4 for monthly growth curves.)

On March 2, 1963, the colt became lame on his right front foot. The foot was cleaned out and no definite lesion was found. It was thought that a bruise was the cause of the lameness. The exercise yard had been changed not long before this, due to construction in the area.

On March 21, 1963, a suppurating lesion was found at the

[1]Fort Dodge Laboratories. Fort Dodge, Iowa.

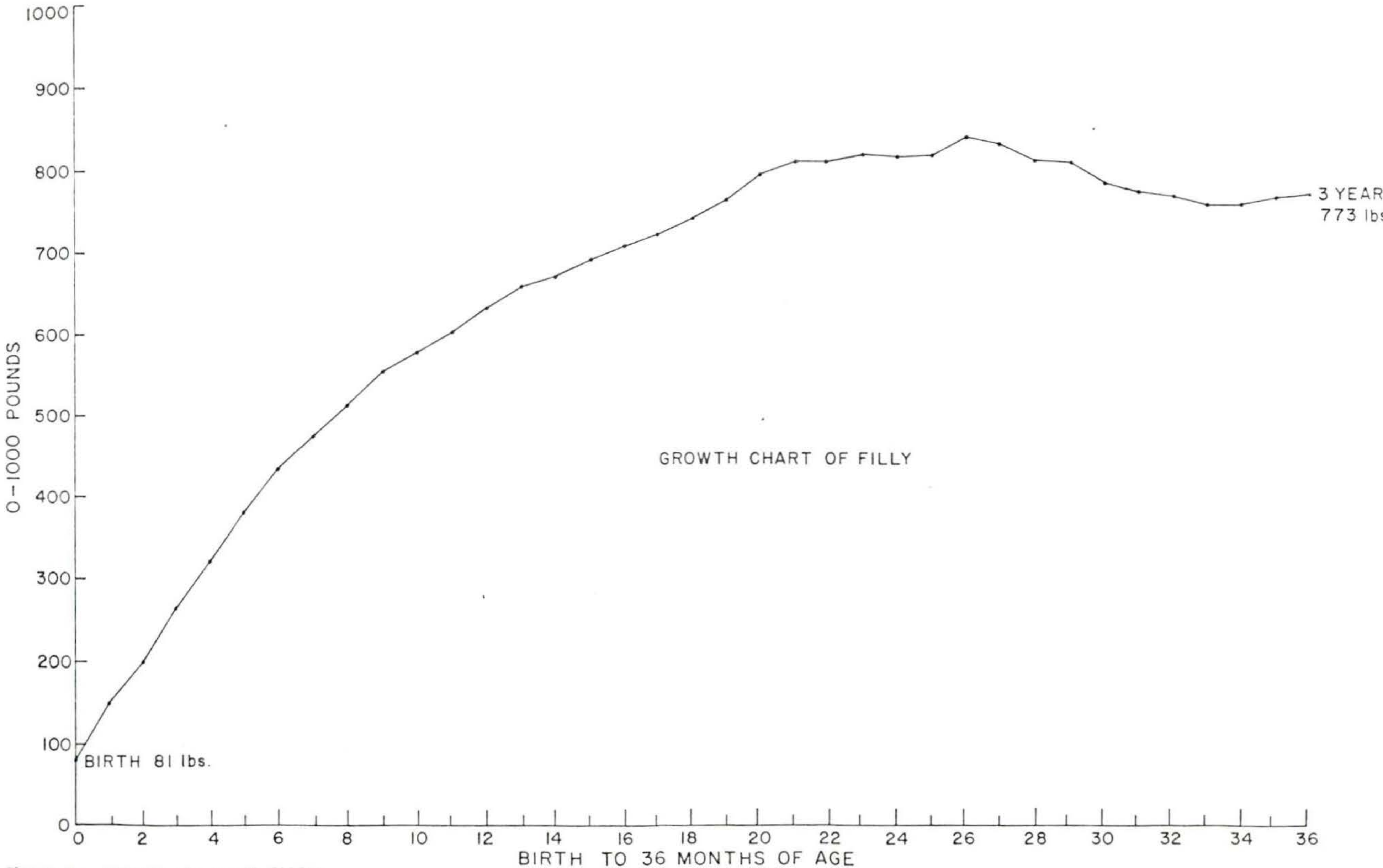


Chart 3. Growth chart of filly

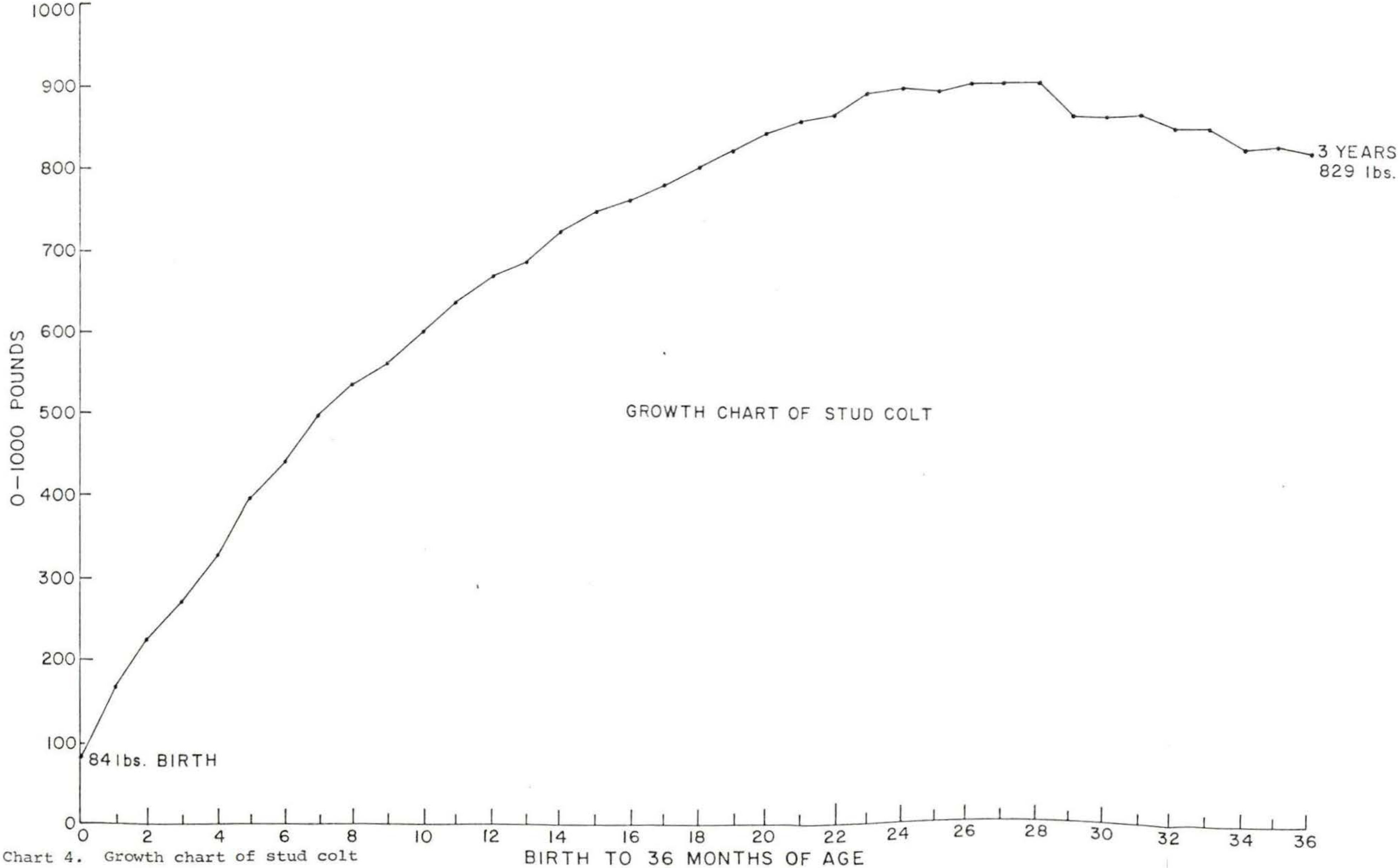


Chart 4. Growth chart of stud colt

posterior aspect of the medial collateral sulcus of the right front foot. The frog was removed around this area and drainage was established. On April 21, 1963, the colt was almost sound after he was shod with shoes and a leather pad. Some loss of weight occurred during this lame period.

A Picker Meteor X-Ray Machine[1] style F10 was used to take the radiographs. The settings varied as the animals grew and their bones became more dense. Par speed cassettes were used in most cases. Lightning speed screens were used to take the shoulder radiographs during the third year. Kodak Medical X-Ray Film[2] Blue Brand was used for all the radiographs except one series, when Kodak Royal Blue Film[2] was used. The time temperature method of development was used. The films were fixed for at least one half hour and were then washed for at least one hour before being dried.

Three hundred and fifty-three radiographs were taken of the front legs of the colt on 44 different occasions between three days of age and three years of age. In the filly radiographs were taken 43 times beginning with the day of birth and ending on May 4, 1963, when she was three years old. During this time a total of 342 radiographs were taken of her front legs (Tables 1 and 2).

---

[1]Picker X-Ray Corporation. White Plains, New York.

[2]Eastman Kodak Company. Rochester, New York.

Table 1. Ages of colt when radiographed in days

3	584
17	612
31	640
52	668
73	696
101	724
129	753
157	781
185	812
213	834
241	859
269	879
297	900
332	920
360	942
388	963
416	982
444	1002
472	1025
500	1052
528	1071
556	1094

Table 2. Ages of filly when radiographed in days

Birth	624
15	652
35	680
56	708
86	735
112	764
140	798
168	820
196	845
229	866
254	887
282	907
315	929
343	950
371	969
427	989
455	1012
487	1039
511	1058
539	1081
567	1095
595	

The nomenclature used to describe the different radiographic views taken was the same as that described by Emmerson[1] and Habel (21).

Anteroposterior (A.P.) radiographs of the front feet were taken on a wooden block two inches by four inches by ten inches. The foot was raised two inches from the ground surface by the block. Lateromedial (L.M.) radiographs of the front feet on the same block were taken. In the anteroposterior view the cassette was behind the foot and as close to it as possible, while in the lateromedial view the cassette was medial to the foot and as close to it as possible. Both of these views included the distal third of the metacarpal bones and the three phalanges. The anteroposterior and lateromedial radiographs of the metacarpal bones usually included a part of or the whole of the carpus. Both lateromedial and anteroposterior radiographs of the carpus were taken if they were not included on other radiographs. Both lateromedial and anteroposterior radiographs of the radius and ulna were taken. These usually included a varying amount of the carpus. In all of the above cases the horses were standing with all four feet squarely under them. The procedures used for taking these radiographs were described by Carlson (9).

---

[1]Emmerson, M. A. Ames, Iowa. Radiographic nomenclature. Private communication. 1962.

Mediolateral (M.L.) radiographs of the elbow joints were taken. The procedure used called for one assistant to pull the leg forward and upward, while a second assistant held the cassette in place on the lateral side of the elbow joint. The X-ray beam was then directed at the cassette from a point just in front of the animal and on the opposite side. A mediolateral view of the shoulder joint was taken in much the same manner. The cassette was centered over the shoulder joint and the leg was extended forward and upward so as to project the air filled trachea over the shoulder joint.

Radiographs were not taken of both front legs on any one occasion. First the left leg was radiographed and then on the next occasion the right leg was radiographed. It was assumed that both legs ossified symmetrically as Tohara (61) stated.

Radiographs of the shoulder were not taken between July 3, 1960, and November 26, 1961, on the colt and between June 29, 1960, and December 21, 1961, on the filly. The elbow joints were not radiographed for the first two months after birth. Part of the elbow joints were included on other radiographs taken during this period. Supplementary radiographs of the elbow joint were taken on two clinic cases at birth, also.

In summary it should be said that these colts were raised as ideally as was possible. They were fed a good ration at all times and were kept in isolation to prevent infectious diseases from interfering with their growth.

The drawings used in this work to represent epiphyseal closures are not tracings. They were used to help illustrate the age and manner of closure. Due to the angle, the radiographs often showed more than one dark line in the epiphyseal line area. In the drawings the dark lines were represented as one line, which in fact they actually were. The drawings are true to scale, but they have been reduced in size.

The criteria used for evaluating complete epiphyseal fusion was the same as that used by Smith (53). Union was considered complete as soon as the dark line of epiphyseal cartilage had disappeared. A white line representing a zone of increased density was present after the disappearance of the dark line. This was called an epiphyseal scar by Smith.

FINDINGS

Third Phalanx

No radiographic signs of an epiphysis were seen in the third phalanx of either foal. (Figures 1 and 2).

Distal Sesamoid

This bone was ossified on the first radiographs taken of both foals and seemed to originate from a single center of ossification. (Figures 1 and 2).

Second Phalanx

Distal end

No radiographic signs of a distal epiphysis of the second phalanx were seen in either the colt or the filly. (Figures 1 and 2).

Proximal end

Colt When the first radiographs were taken at three days of age the epiphyseal line between the proximal epiphysis of the second phalanx and the diaphysis was a solid smooth dark line. The epiphyseal line ran transversely through the long axis of the bone on both the anteroposterior and the lateromedial views. The first signs of ossification of this epiphyseal line were seen when the colt was 129 days old. The epiphyseal line had begun to disappear in the center of the bone. This epiphyseal line fused in the center first and then proceeded to ossify outwardly. At 185 days of age the

A. Birth
1. Diaphysis of 3rd metacarpal bone
2. Distal epiphysis of 3rd metacarpal bone
3. Proximal epiphysis 1st phalanx
4. Diaphysis 1st phalanx
5. Proximal epiphysis 2nd phalanx
6. Diaphysis 2nd phalanx
7. 3rd phalanx

B. 86 days old

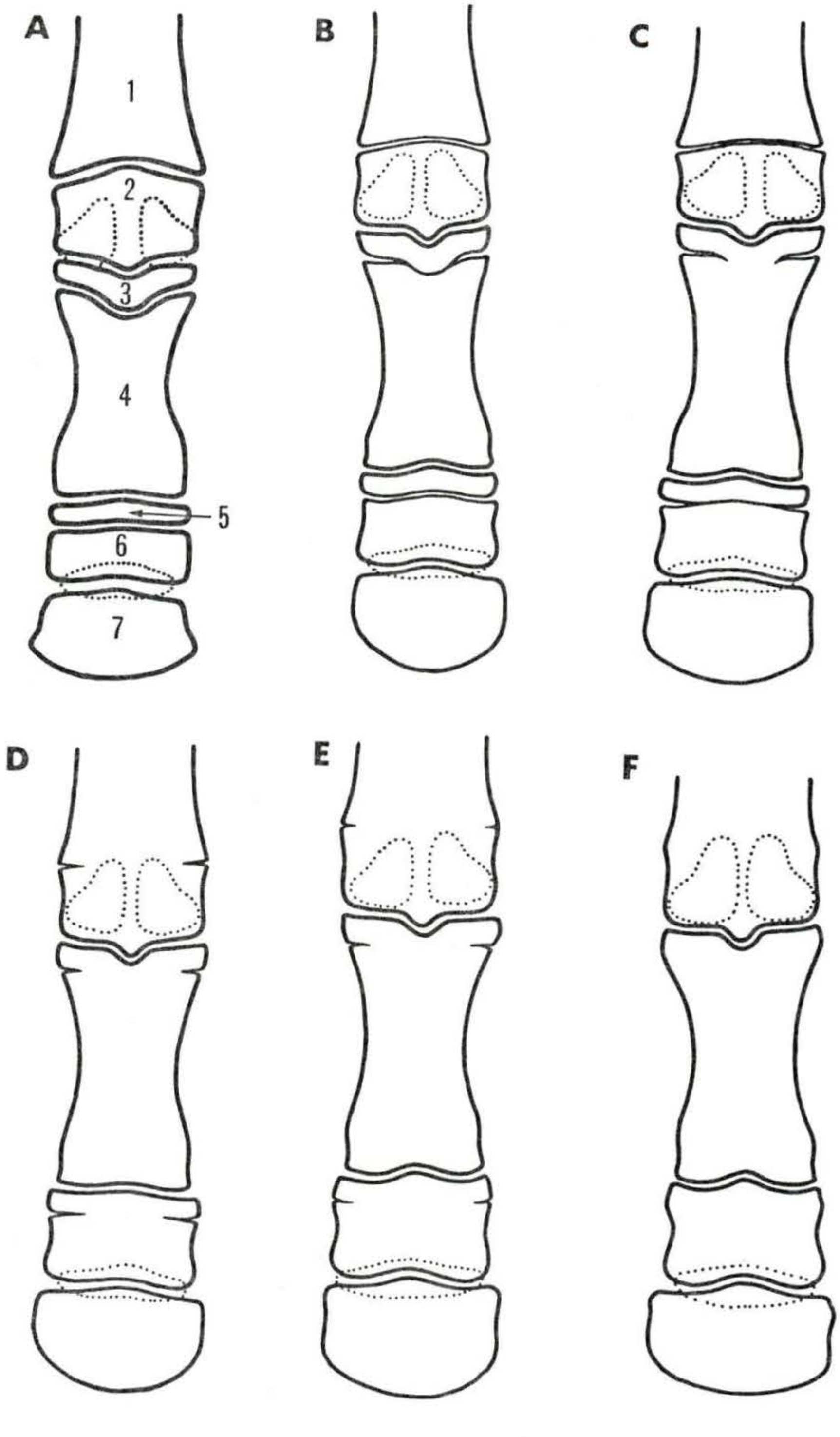
C. 140 days old

D. 168 days old

E. 196 days old

F. 229 days old complete closure

Figure 1. Filly, anteroposterior view of the foot


A
1
2
3
4
5
6
7
B
C
D
E
F

A. Birth

1. Diaphysis of 3rd metacarpal bone
2. Distal epiphysis of 3rd metacarpal bone
3. Proximal epiphysis 1st phalanx
4. Diaphysis 1st phalanx
5. Proximal epiphysis 2nd phalanx
6. Diaphysis of 2nd phalanx
7. 3rd phalanx

B. 86 days old

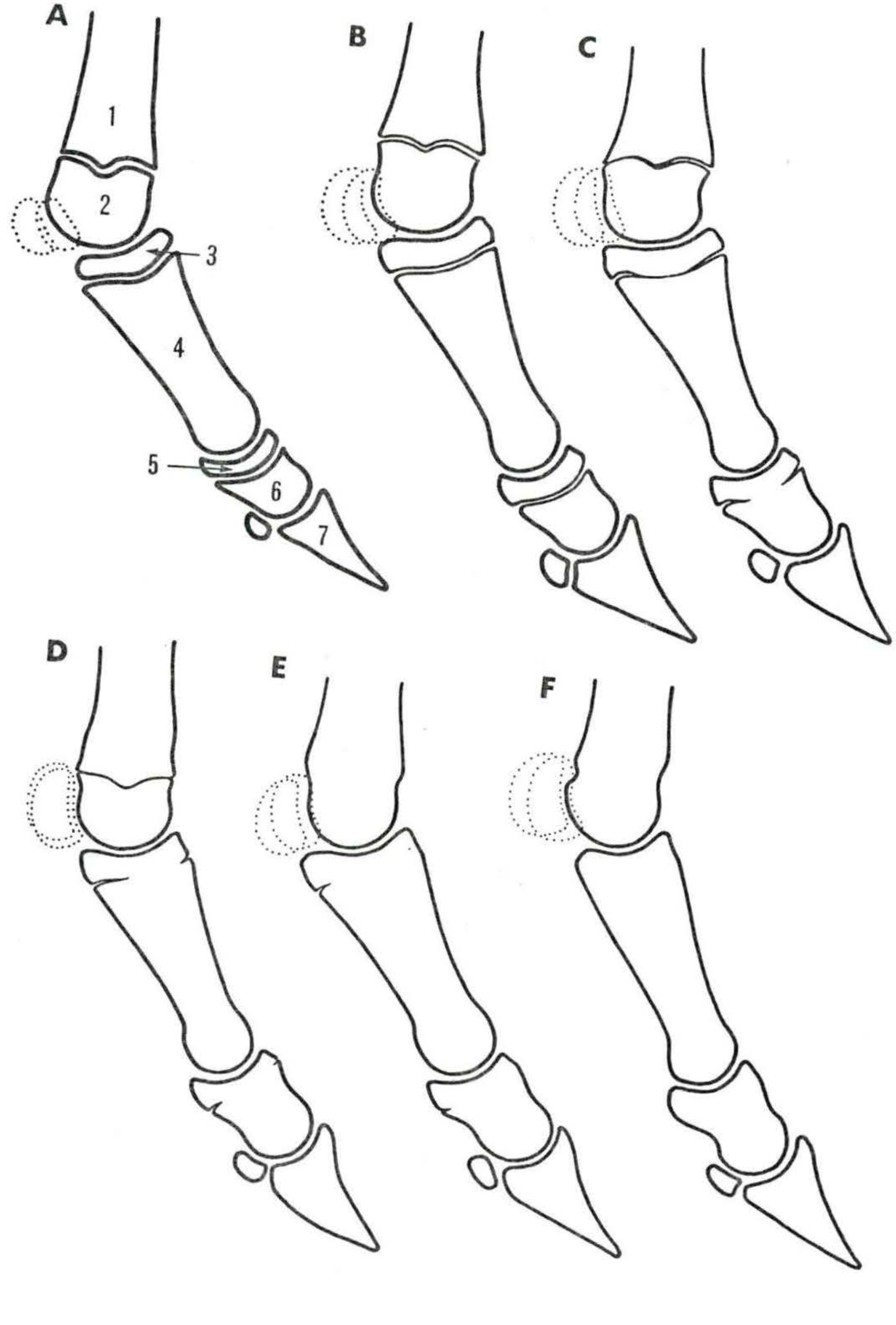
C. 140 days old

D. 168 days old

E. 196 days old

F. 229 days old

Figure 2. Filly, lateromedial view of foot


A
B
C
D
E
F
1
2
3
4
5
6
7

the proximal epiphysis was closed except on the posterior surface of the lateromedial view and on the medial and lateral surface of the anteroposterior view. By 213 days the epiphyseal line was almost fused, but the outside edges of the anteroposterior view were still slightly darker than the rest of the bone. After 241 days no signs of the proximal epiphyseal line of the second phalanx were seen on either the anteroposterior or the lateromedial views of the colt's foot. (Figures 1 and 2).

Filly The radiographic appearance of this epiphyseal line at birth in the filly was similar to that of the colt's at three days of age. In the filly the proximal epiphyseal line of the second phalanx began to close in the center by the 140th day after birth. After 196 days the lateromedial view showed only the posterior end of the epiphyseal line open, while the anteroposterior view showed both the lateral and medial edges open. After 229 days the proximal epiphyseal line of the second phalanx of the filly was completely closed. (Figures 1 and 2).

First Phalanx

Distal end

Colt Definite signs of a distal epiphyseal line were seen on the radiographs taken when the colt was three days old. On both the anteroposterior and the lateromedial views, the cortex of the bone was fused, but a thin dark line was still present at the center of the epiphyseal line. This dark line was barely visible after 17 days and it had completely disappeared by the 31st day after birth. A zone of increased density was still present in the area of epiphyseal closure on the 31st day.

Filly The distal epiphyseal line of the first phalanx was represented as a zone of increased density in the filly at birth. No dark line was visible, but the zone of increased density suggested that this epiphyseal line had closed recently.

Proximal end

Colt At three days of age the proximal epiphysis of the first phalanx was separated radiographically from the diaphysis by a solid dark epiphyseal line. On the lateromedial view this line had a slight distal convexity, while on the anteroposterior view it was transverse to the long axis of the bone on the lateral and medial sides and had a definite distal depression in the center (Figures 1, 2, 3, and 4). It was in the area of this depression in the center of the anteroposterior view where fusion first began. The last sign of the epiphyseal line at the central depression was gone by the 157th day. The lateromedial view at 157 days still showed an open epiphyseal line, but it was very narrow and indistinct in the center. At 185 days and also at 213 days the lateromedial view showed only the posterior edge of

A. Birth
1. Diaphysis of 3rd metacarpal bone
2. Distal epiphysis of 3rd metacarpal bone
3. Proximal epiphysis 1st phalanx
4. Diaphysis 1st phalanx

B. 86 days old

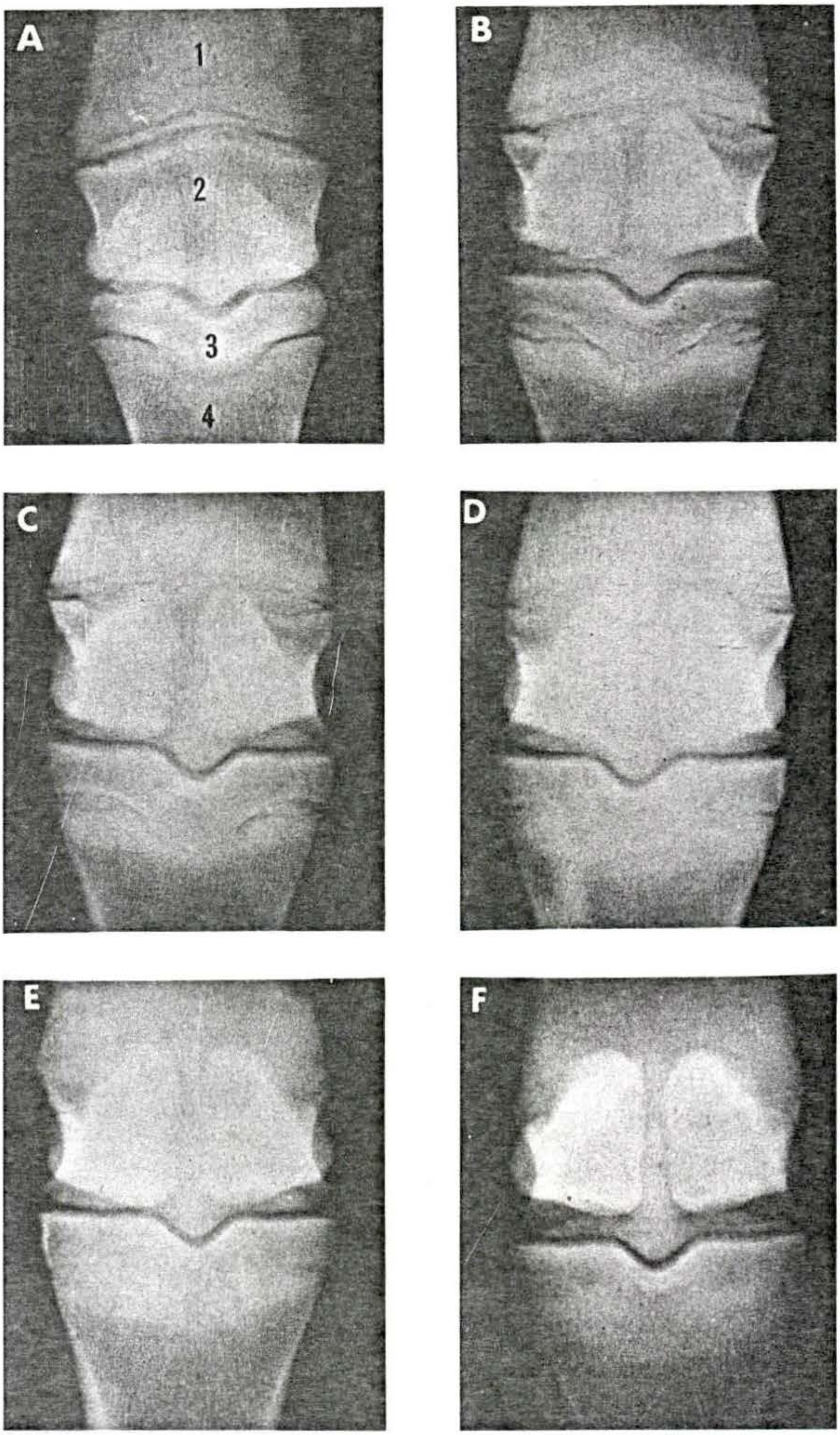
C. 140 days old

D. 168 days old

E. 196 days old

F. 229 days old
complete closure

Figure 3. Anteroposterior view of fetlock joint, filly


A
1
2
3
4
B
C
D
E
F

A. Birth
1. Diaphysis of 3rd metacarpal bone
2. Distal epiphysis of 3rd metacarpal bone
3. Proximal epiphysis 1st phalanx
4. Diaphysis 1st phalanx

B. 86 days old

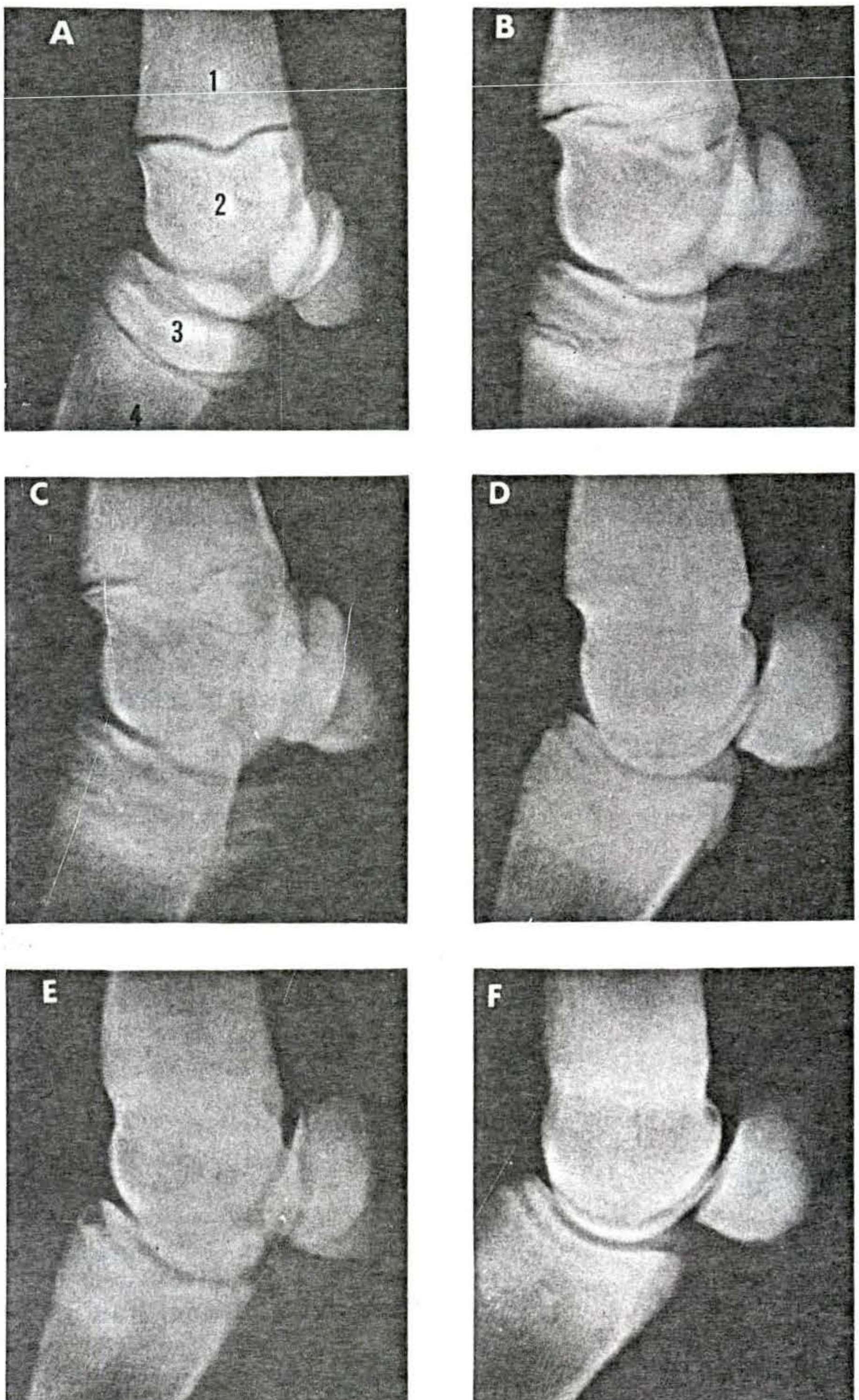
C. 140 days old

D. 168 days old

E. 196 days old

F. 229 days old

Figure 4. Lateromedial view of fetlock joint, filly


A
1
2
3
4
B
C
D
E
F

the epiphyseal line open. On the anteroposterior view at these same ages the lateral and medial edges of the bone were open. Complete closure of this epiphyseal line was found in the colt after 269 days, but not after 241 days.

Proximal end

Filly The central depression on the anteroposterior view began to close after 140 days in the filly. On the lateromedial view at the same age the epiphyseal line was very narrow in the center, but it remained open. After 168 days, both views showed the center of the bone united. On the anteroposterior view after 196 days, both the lateral and medial sides were open, but they were closed by 229 days. On the lateromedial view, only the posterior edge was open at 196 days and it had closed by 229 days (Figures 1, 2, 3, and 4).

Proximal Sesamoids

These bones were ossified in the first radiographs taken of both foals and their growth after birth was limited to the appositional type (Figures 1, 2, 3, and 4).

Third Metacarpal Bone

Distal end

Colt A slight proximal convexity of the distal epiphyseal line of the third metacarpal bone was noted on the anteroposterior view (Figures 1 and 3). On the lateromedial view the epiphyseal line had a central depression (Figures 2 and 4). Schmidt (48) called the lateromedial view of this epiphyseal line "butterfly wing shaped". Both of these views showed a narrow, but solid dark line present after 157 days. A rapid change then took place and by 185 days the line was almost completely closed. A very indistinct line remained on the anterior part of the lateromedial view and on the lateral and medial edges of the anteroposterior view. This epiphyseal line was completely fused by the 213th day after parturition in the colt.

Distal end

Filly The distal epiphyseal line of the third metacarpal bone of the filly had begun to close in the center on both the anteroposterior and lateromedial views by the 168th day. On the lateromedial view it was completely closed on the 196th day, while the edges remained open at that age on the anteroposterior view. Both views showed complete closure by the 229th day (Figures 1, 2, 3, and 4).

Proximal end

No radiographic signs of a proximal epiphysis of the third metacarpal bone were seen in this study.

Second and Fourth Metacarpal Bones

No radiographic evidence of a proximal or a distal epiphysis was visible on these radiographs.

Carpal Bones

All of the carpal bones were calcified in both foals on the first radiographs and they showed no evidence of any secondary centers of ossification.

Radius and Ulna

Distal end

Colt The first radiographs of the colt showed the distal epiphysis of the radius and the small wedge shaped epiphysis that represented the distal end of the ulna separated by an epiphyseal line. On the anteroposterior view, the ulnar epiphysis was situated laterally to the radial epiphysis, while on the lateromedial view it lay posterior and slightly distal to the radial epiphysis. On both views the ulnar epiphysis overlapped the distal radial epiphysis and the accessory carpal bone. After 101 days the proximal end of the epiphyseal line between the radial and ulnar epiphyses was fused on the anteroposterior view and the two ends were fused on the lateromedial view. This epiphyseal line was still open in the center on the 241st day on the anteroposterior view, but it was not visible on the lateromedial view. By the 269th day no radiographic signs of this epiphyseal line remained (Figures 5 and 6).

The distal radial epiphysis began to fuse to the diaphysis on the 584th day on the lateromedial view and on the 612th day on the anteroposterior view. It then proceeded to close from the center outward in a rapid manner. The lateromedial view showed complete closure by the 696th day, while the anteroposterior view did not show complete closure until

A. 3 days old
1. diaphysis of radius
2. distal epiphysis of radius
3. distal epiphysis of ulna

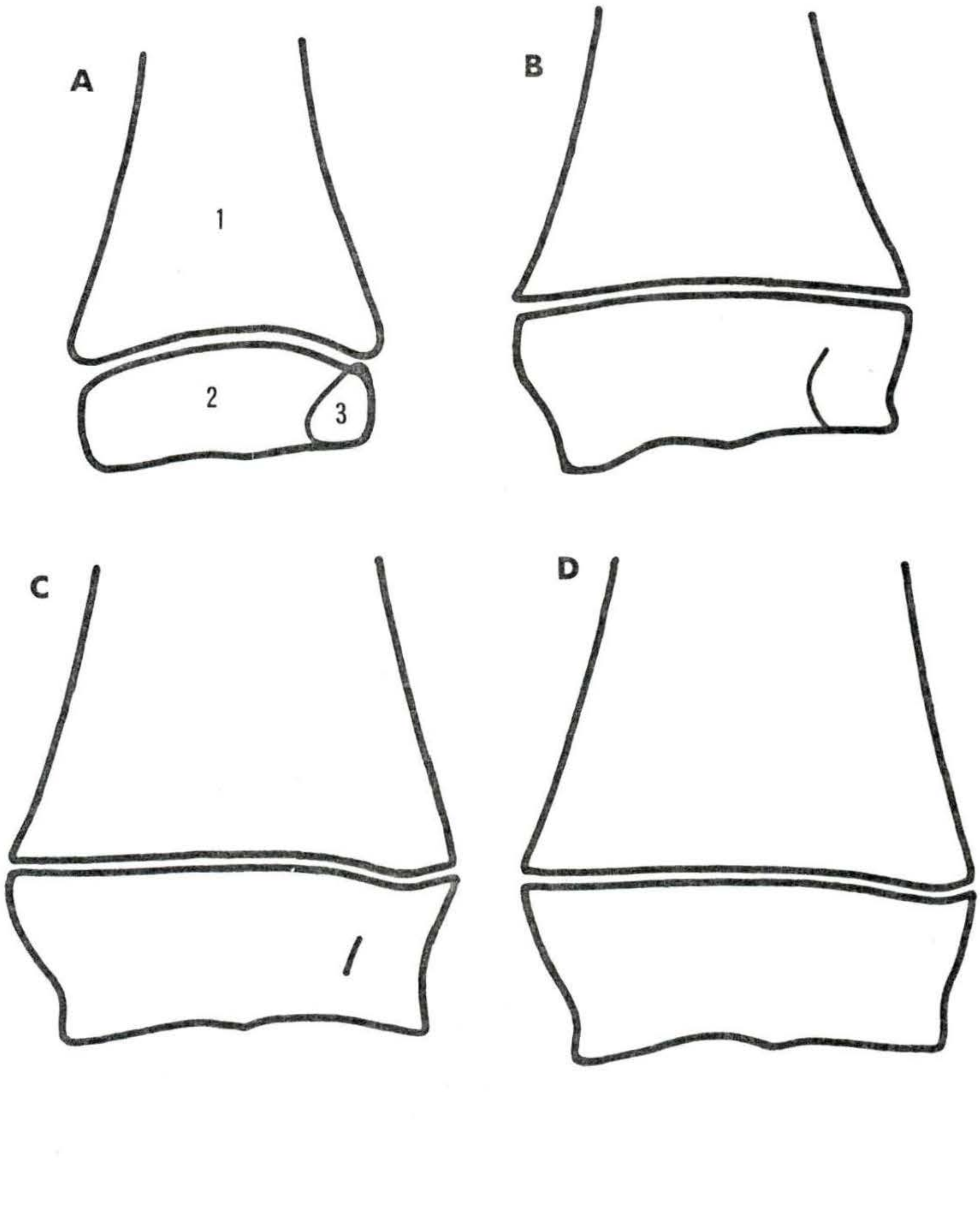
B. 101 days old

C. 241 days old

D. 269 days old

Continued on Page 43

Figure 5. Colt, anteroposterior view of distal end of radius


A
1
2
3
B
C
D

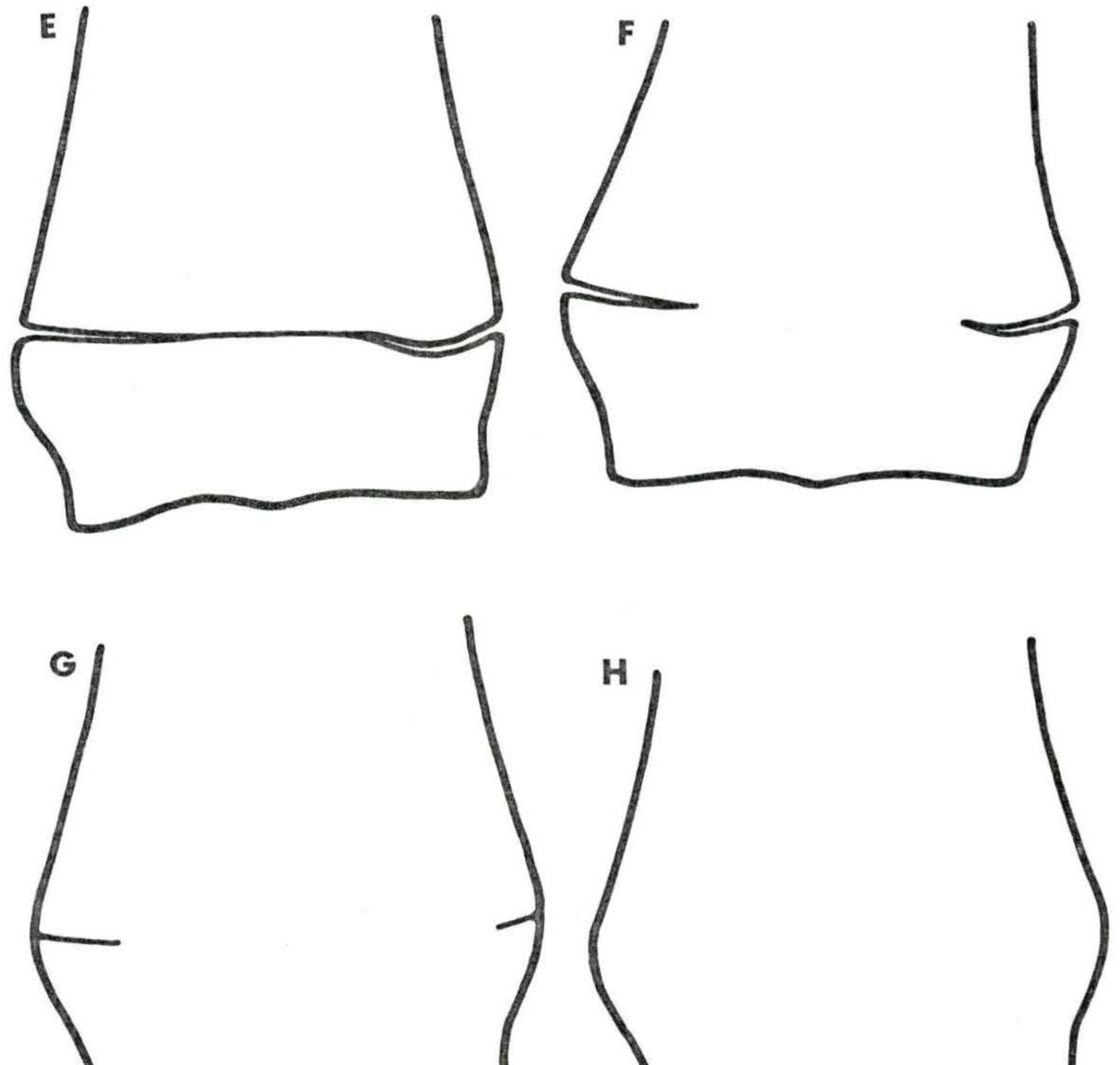
E. 584 days old

F. 612 days old

G. 668 days old

H. 724 days old

Figure 5. (Continued)


E
F
G
H

A. 3 days old
1. Diaphysis of radius
2. Distal epiphysis of radius
3. Distal epiphysis of ulna

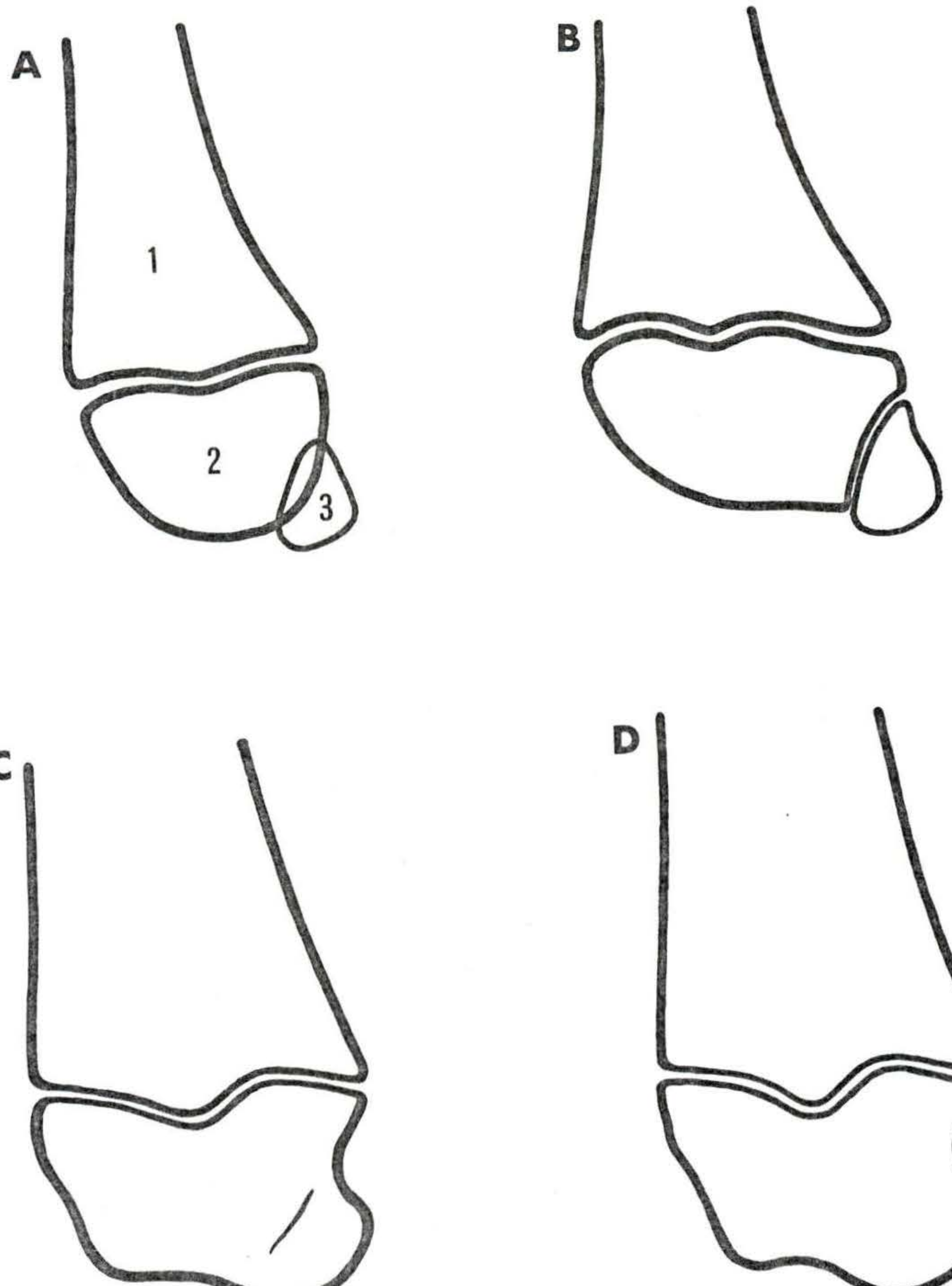
B. 31 days old

C. 101 days old

D. 241 days old

Continued on Page 47

Figure 6. Colt, lateromedial view of distal end of radius


A
1
2
3
B
C
D

E. 556 days old

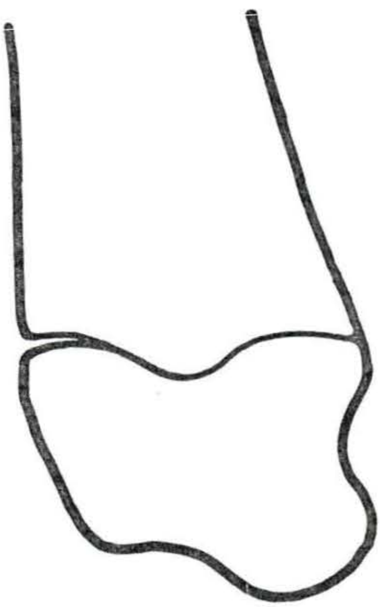
F. 584 days old

G. 640 days old

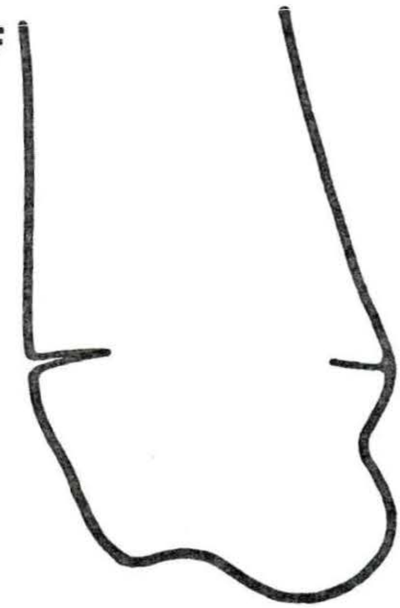
H. 696 days old

Figure 6. (Continued)

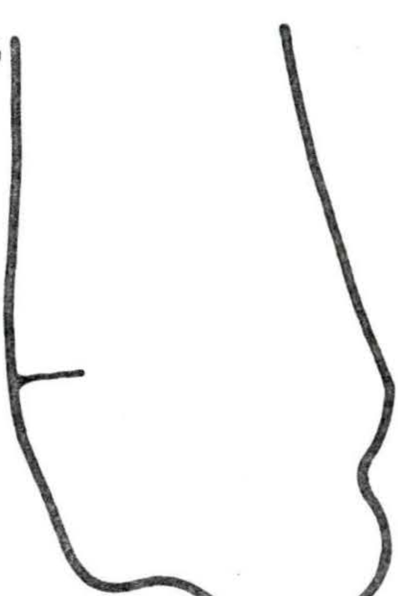
E



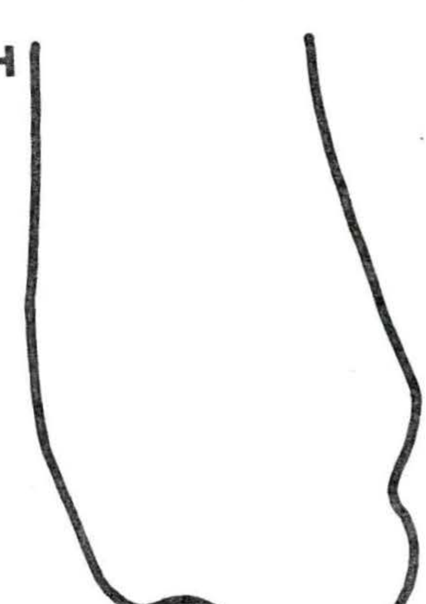
F



G



H



the 724th day (Figures 5 and 6).

Filly The wedge-shaped bone that represents the distal end of the ulna did not begin to unite to the distal radial epiphysis until the 112th day. By this date the proximal apex had fused to the distal radial epiphysis. Complete closure of this epiphyseal line was noted on the 196th day.

Narrowing of the distal radial epiphyseal line was evident by the 487th day, but complete closure of the center of this line was not observed until the 624th day. Closure then proceeded rapidly and no epiphyseal line was visible on the 708th day.

Radius

Proximal end

Colt The proximal epiphyseal line of the radius was still a solid single dark line on the 241st day after birth. Between the 269th day and the 388th day the posterior seven-eighths of the epiphyseal line slowly united and only the anterior one-eighth was left open. By the 416th day complete epiphyseal closure had taken place. The radial tuberosity, which arose on the anterior edge of this epiphyseal line was not completely smoothed anteriorly until the 900th day.

Filly Although very narrow the proximal radial epiphyseal line was still completely open on the 343rd day. This line remained open on the posterior and anterior ends on the 371st day, but it was closed in the center. By the 427th day, complete closure of this epiphyseal line had become evident. The radial tuberosity did not become smooth anteriorly until the 907th day (Figure 7).

Ulna

Proximal end

Colt The proximal ulnar epiphysis was seen on the radiographs of the thorax of the colt when he was three days old. It was a small center of ossification which was situated proximally to and on the posterior edge of the ulnar diaphysis. By the 101st day this epiphysis had increased markedly in size. The proximal ulnar epiphyseal line was very narrow posteriorly on the 612th day, but it was still completely open. On the 640th day the anterior three-fourths of the line was closed, but the posterior quarter was open. The posterior part of this line was not completely fused until the 812th day.

Filly The proximal ulnar epiphysis was already ossified at birth in the filly. This epiphyseal line was still completely open on the 624th day, but the anterior three fourths was very narrow and irregular. Only a small area on the posterior border remained open on the 680th day. Complete closure did not take place until the 907th day (Figure 7).

A. Birth (clinic case)
1. Diaphysis of humerus
2. Epiphysis of medial epicondyle
3. Distal epiphysis of humerus
4. Proximal epiphysis of ulna
5. Diaphysis of ulna
6. Proximal epiphysis of radius
7. Diaphysis of radius

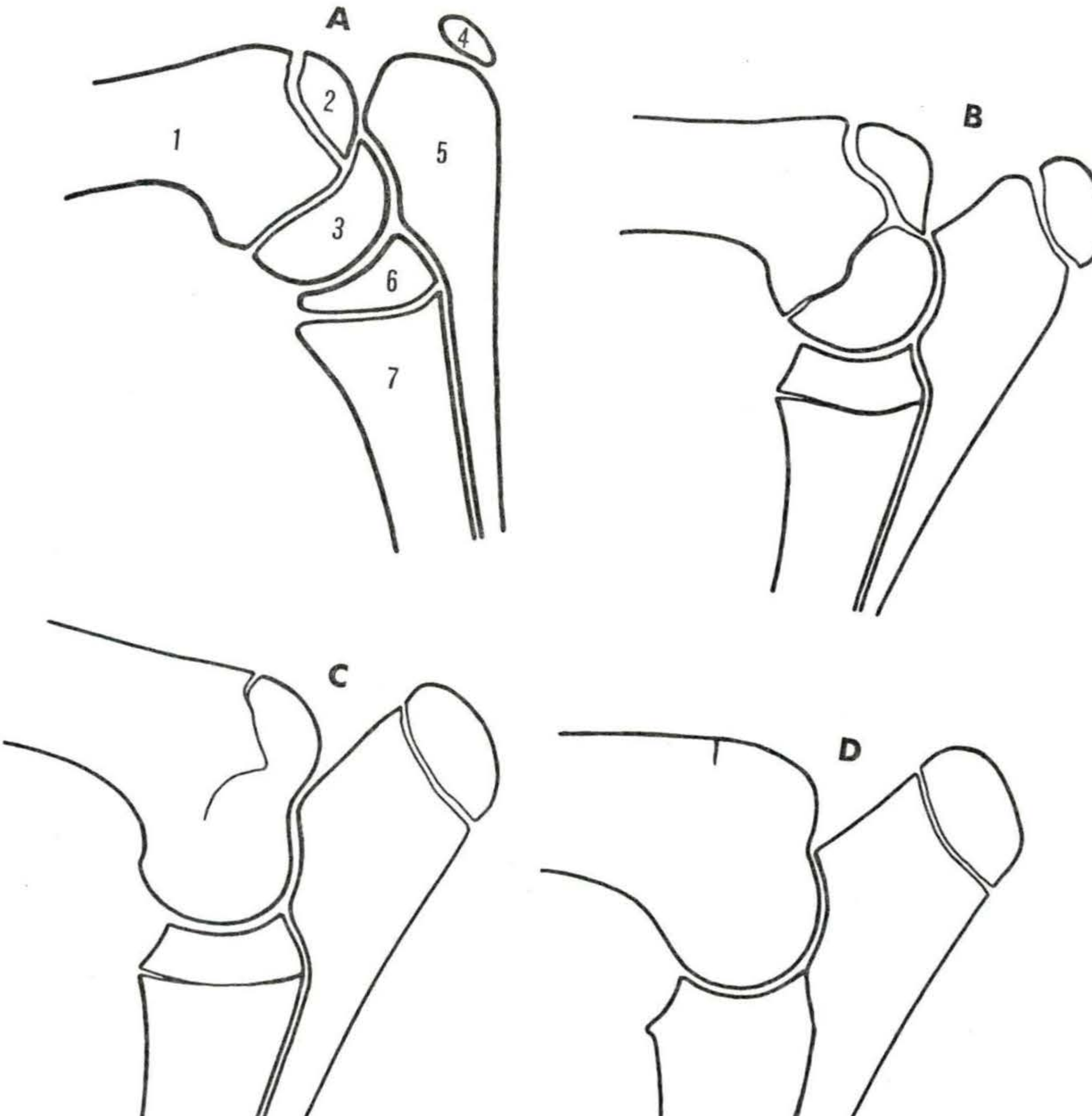
B. 140 days old

C. 343 days old

D. 427 days old

Continued on Page 53

Figure 7. A. clinic case, B - H. filly, mediolateral of elbow joint


A
1
2
3
4
5
6
7
B
C
D

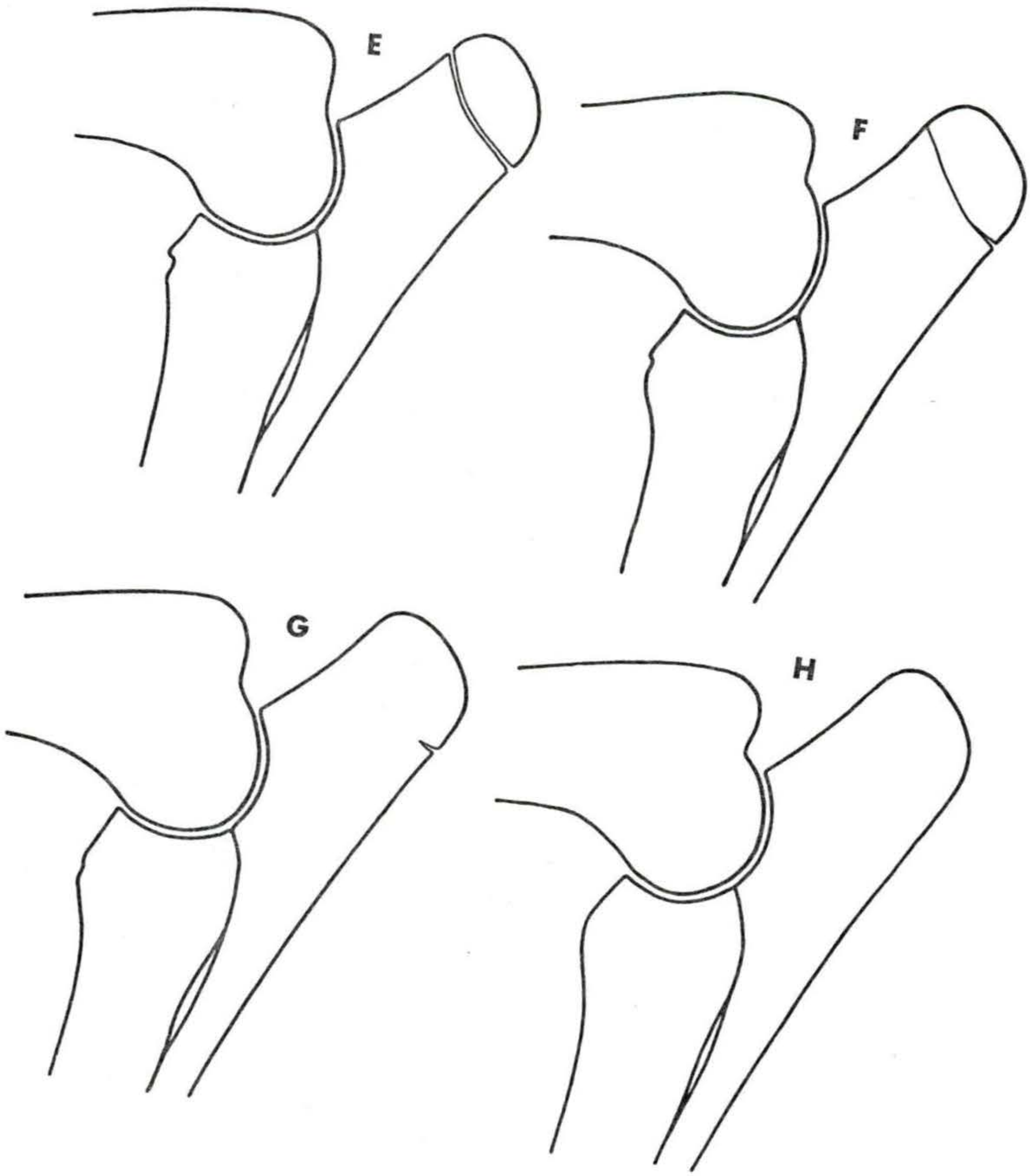
E. 487 days old

F. 624 days old

G. 680 days old

H. 907 days old

Figure 7. (Continued)


E
F
G
H

Humerus

Distal end

Colt The distal epiphysis and the epiphysis of the medial epicondyle were completely ununited after 129 days in the colt. These two secondary centers of ossification had united with each other by the 185th day. They were both separated from the diaphysis of the humerus at this age. On the 241st day the distal epiphysis had begun to fuse to the diaphysis in the center of the bone. After 332 days this epiphyseal line was completely closed, but the posterior half of the epiphyseal line between the medial epicondyle and the diaphysis remained open. This epiphyseal line was completely closed on the 416th day.

Filly On the 196th day the epiphyseal line between the distal epiphysis and the diaphysis had fused in the center, but the medial epicondyle had not fused to the distal epiphysis. These two secondary centers of ossification were united by the 254th day. By the 371st day (about one year) the distal epiphyseal line was completely fused. The epiphyseal line between the medial epicondyle and the humeral diaphysis fused from the center toward the cortex. This epiphyseal line was no longer visible on the 455th day after birth (Figure 7).

Humerus

Proximal end

Colt At three days of age there were two centers of ossification at the proximal end of the humerus (Figure 8-A). The anterior center of ossification was the epiphysis of the lateral tuberosity and the posterior center of ossification was the proximal epiphysis of the humerus. By the 17th day, the medial tuberosity of the humerus had begun to ossify (Figure 8-B). The ossification of the medial tuberosity proceeded rapidly once it had begun. No epiphyseal union was seen on the 73rd day after birth. By the 584th day when radiographs of this area were resumed, the proximal epiphysis of the humerus was fused to the diaphysis, but the lateral tuberosity was not fused to the diaphysis on its anterior border. This line did not close until the 812th day (Figure 8).

Filly The radiographs of the filly contained the same two epiphyses as the colt. On the 15th day the medial tuberosity was just beginning to ossify. No epiphyseal union was found on the 56th day. The next radiograph was taken on the 595th day and it showed only the anterior border of the epiphyseal line between the lateral tuberosity and the diaphysis open. This epiphyseal line had completely fused by the 798th day after birth.

A. 3 days old
1. Diaphysis of scapula
2. Epiphysis of coracoid process
3. Second ossification zone
4. Proximal epiphysis of humerus
5. Epiphysis of lateral tuberosity
6. Diaphysis of humerus

B. 17 days old
7. Medial tuberosity

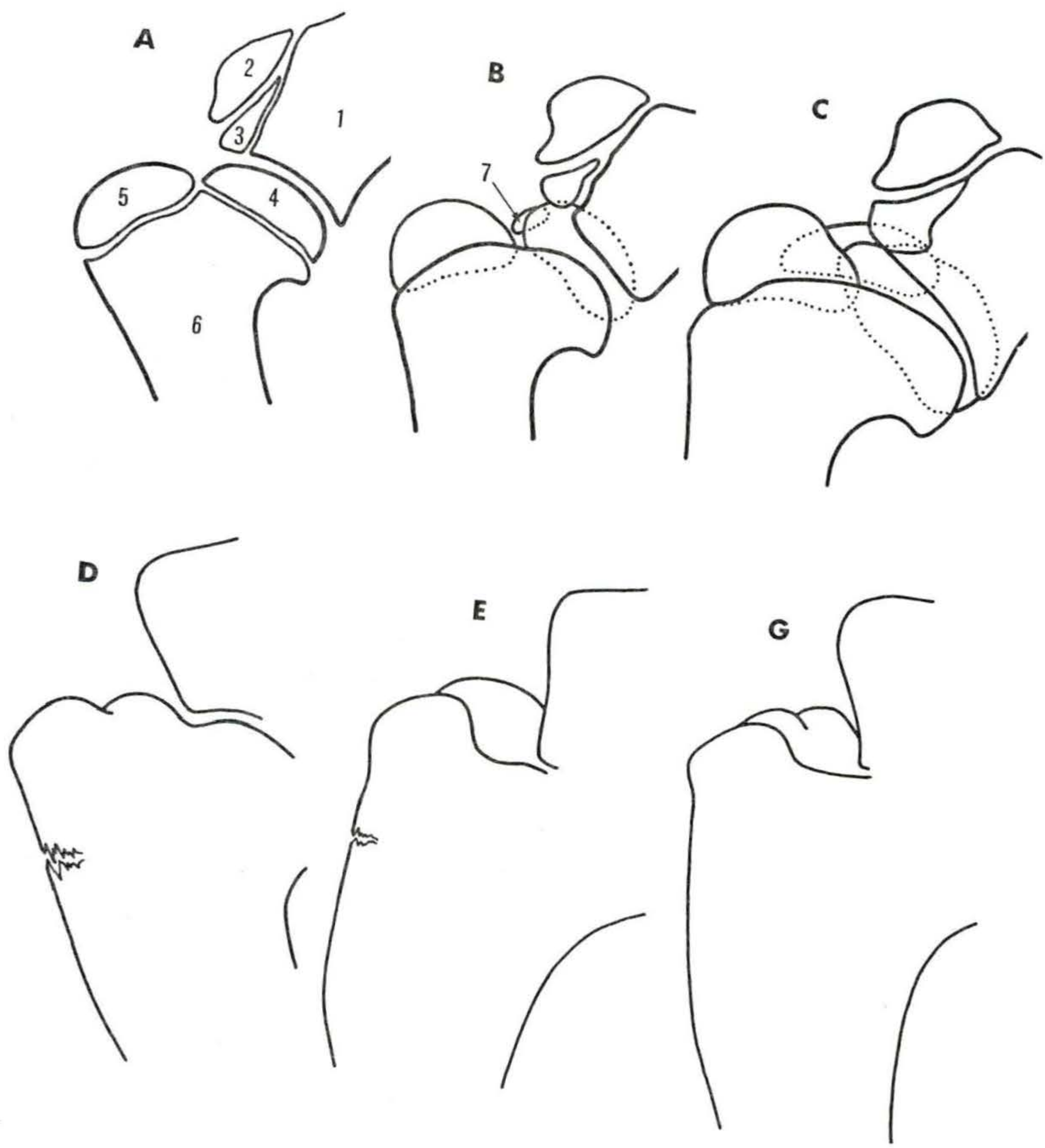
C. 52 days old

D. 584 days

E. 753 days

F. 812 days

Figure 8. Colt, mediolateral view of shoulder joint


A
2
3
1
5
4
6
B
7
C
D
E
G

Scapula

Distal end

Colt   On the 3rd day there were two centers of ossification on the distal end of the scapulae (Figure 8-A). The anterior center was thought to be the center of ossification of the coracoid process and the second center, the center of ossification of part of the tuber scapula. These centers were ununited after 73 days. These centers fused to the diaphysis sometime between the 73rd day and 584th day, when this radiographic view was taken next (Figure 8).

Filly   The two centers of ossification seen in the colt were also seen in the filly until the 15th day. After the 15th day no clear radiograph was found until the 595th day when no signs of the open epiphyseal line were present.

DISCUSSION

Two tables were prepared to help with the discussion of epiphyseal closure times. Table 3 was compiled to show the anatomical closure times given by Sisson and Grossman (52), Lesbre (32), Zietzschmann and Krölling (66), and Rooney (42). Table 4 was made to compare the radiographic closure times of Tohara (61) and Schmidt (48) with those found in this study. The colt and the filly were kept separate in this table to allow better comparison.

The radiographic closure times of the proximal end of the second phalanx were found to be similar to those of Tohara, but were about one month later than those found by Schmidt. The radiographic closure times were two to three months earlier than the anatomical closure ages. The closure times of the colt and the filly were almost identical for this epiphyseal line, the former being by the 241st day and the latter by the 229th day.

The distal epiphysis of the first phalanx was united at birth in the filly, but did not unite until sometime between the 17th and 31st day in the colt. This epiphyseal line was not seen by Schmidt or Tohara after birth. Anatomically Sisson and Grossman stated it was closed before birth, while the other anatomical works stated it closed after birth.

The proximal epiphysis of the first phalanx was united to the diaphysis earlier in the filly (229 days) than in the colt (269 days). Again these unions agreed closely with those of Tohara, but were later than those of Schmidt. The radiographic closure times again were in advance of the anatomical closure times.

There was considerable difference between the age Tohara gave for closure of the distal epiphyseal line of the third metacarpal bone and the ages determined in this study. Tohara stated that closure took place in the 17th to 18th months. This was more than twice as long as this study showed and almost three times longer than Schmidt had reported. This epiphysis was fused by the 213th day in the colt and by the 229th day in the filly. Tohara's fusion time agreed with the anatomical time given by Sisson and Grossman, but was longer than the times given by the other anatomical references.

The distal epiphysis of the ulna was not completely fused to the distal radial epiphysis in these foals until the 196th and 269th days. This was 2½ and 5 months longer than Schmidt had found and it was more than twice as long as Lesbre's anatomical study had shown. In the colt this union took place 2½ months earlier than in the filly.

The proximal epiphysis of the ulna was ossified in both these foals at birth. This agreed with Tohara, but not with Küpfer. This epiphysis was fused on the 812th day in the colt and on the 907th day in the filly, which was earlier than the "about 3½ years" reported in all the anatomical studies. The closure was completed more than three months later in the filly than in the colt in this study. Schmidt did not determine the fusion time of this epiphysis.

The distal epiphysis of the radius was fused on the 726th day in the colt and on the 708th day in the filly. This is just a few days less than two years of age in both horses. All of the anatomical studies stated this fusion occurred at "about 3½ years", while Schmidt said it was closed by the age of 3 years. The "epiphyseal scar" reported by Smith (55) was present in the area of this epiphyseal line in both horses on their third birthdays. The width of this scar continually decreased after union, but it was still present at age three.

The proximal epiphysis of the radius was said to be fused before one year of age by Schmidt. It was fused in the colt by the 416th day and in the filly by the 427th day. These ages were just slightly less than the 15 to 18 months reported in the anatomical studies.

Epiphyseal closure times for both the medial epicondyle and the distal epiphysis of the humerus were given in this study. In all the other works cited, only a closure time for the distal epiphysis of the humerus was given. Whether these workers actually referred to the later closing epiphyseal line of the medial epicondyle was not stated.

The distal epiphysis of the humerus was united to the diaphysis by the 332nd day in the colt and by the 371st day in the filly, but the medial epicondyle did not fuse until the 416th day in the colt and the 455th day in the filly. The latter agreed with the 15 to 18 months given in the anatomical reports, but were later than the "before one year" given by Schmidt.

At the proximal end of the humerus two epiphyses were described and again the anatomical reports did not say if they were referring to one or both of these epiphyses. It was assumed that their "about 3½ years" referred to both epiphyseal lines, since the proximal epiphysis of the humerus was fused sometime before the 21st month in both of these horses. The lateral tuberosity of the humerus was completely fused in the colt by the 812th day and in the filly by the 798th day. Schmidt did not establish closure times for this area. The medial tuberosity of the humerus was found to ossify separately from the lateral tuberosity and it was still separate at the end of the second month.

The coracoid process of the scapula was fused sometime before the 21st month in both these foals, but no definite fusion time was determined. Schmidt said this fusion took place before the 18th month and the anatomical studies gave a fusion time between 10 and 12 months.

Table 3. Anatomical epiphyseal closure times

	Zietzschmann & Krölling Rooney	Lesbre	Sisson & Grossman
Scapula			
Coracoid process	10 m. - 1 yr.	10 m. - 1 yr.	about 1 yr.
Humerus			
Proximal epiphysis	about 3½ years	about 3½ yrs.	about 3½ yrs.
Lateral tuber.			
Distal epiphysis	15-18 m.	15-18 m.	about 1½ yr.
Medial epicondyle			
Radius			
Proximal	15-18 m.	15-18 m.	about 1½ yr.
Distal	about 3½ yrs.	3½ yrs.	about 3½ yrs.
Ulna			
Proximal	about 3½ yrs.	3½ yrs.	about 3½ yrs.
Distal	?	2-3 m.	before birth
3rd Metacarpal			
Distal	10-12 m.	about 15 m.	middle of 2nd yr.
1st Phalanx			
Proximal	12-15 m.	12-15 m.	about 1 yr.
Distal	1 wk. after birth	some wks. after birth	at birth
2nd Phalanx			
Proximal	10-12 m.	10-12 m.	9-10 m.

Table 4. Radiographic epiphyseal closure times

	Tohara	Schmidt	Colt	Filly
Scapula				
Coracoid process		sometime before 18 m.	before 584 days	before 595 days
Humerus				
Proximal epiphysis		?	before 584 days	before 595 days
Lateral tuberosity			812 days	798 days
Distal epiphysis		before 1 yr.	332 days	371 days
Medial epicondyle			416 days	455 days
Radius				
Proximal		before 1 yr.	416 days	427 days
Distal		3 yrs.	724 days	708 days
Ulna				
Proximal		?	812 days	907 days
Distal		before 4 m.	269 days	196 days
3rd Metacarpal				
Distal	17th-18th m.	6 m.	213 days	229 days
1st Phalanx				
Proximal	9th-10th m.	6 m.	269 days	229 days
Distal	at birth		31 days	before birth
2nd Phalanx				
Proximal	7th-8th m.	6 m.	241 days	229 days

SUMMARY AND CONCLUSIONS

1. This radiographic study of the epiphyseal closure times in the front legs of the horse followed two foals from birth to three years of age. The two Arabians used for this study were closely related and inbred. The foals were kept in isolation and fed a ration considered more than adequate throughout the entire three years. A colt and a filly were used so that a comparison of the sexes could be made.

Earlier radiographic studies were not in agreement with each other or the anatomical closure times given in textbooks. None of these studies followed an individual animal through its development, but used various horses of different ages.

2. No sex difference in epiphyseal closure times was noted in this study. The filly had an earlier closure time in six of the 13 areas studied and the colt had an earlier closure time in five of the areas. In two of the areas no conclusions could be reached, since continuous radiographs were not taken.

3. See Table 4, Page 65 for a summary of the epiphyseal closure times of the colt and the filly.

4. The last epiphyseal line was closed in the filly by the 907th day after birth. This was the proximal epiphyseal line of the ulna. In the colt both the proximal epiphysis of the ulna and the lateral tuberosity of the humerus were first seen fused to their diaphyses on the 812th day. These were the last epiphyseal lines to fuse in the colt. It was thus

concluded that all growth in length of the forelimbs of these two horses was completed before they were two and one half years old.

5. It was found that the distal epiphysis of the first phalanx can be fused or partially open at birth. This epiphyseal line was closed at birth in the filly, but was open in the center in the colt at three days of age. Complete closure was observed by the 31st day in the colt.

6. The epiphyseal closure times of the ulna varied between the colt and the filly more than any of the other closure times. Fusion of the proximal end of the ulna occurred first in the colt, while the distal end of the ulna was fused first in the filly.

7. The radiographic closure times of this study were earlier than the anatomical times in Table 1, with two exceptions. The radiographic fusion of the distal epiphyses of the radius and the ulna in both the colt and the filly occurred at a later date than reported in the anatomical studies. The fusion of the distal epiphysis of the first phalanx fused in the colt after birth, while Sisson and Grossman claimed fusion took place before birth.

8. The chronological order of epiphyseal fusion of the front legs in both the colt and the filly was very similar. The fusion of the distal ends of the radius and the ulna were not in the same order in these foals. Fusion of the open

epiphyseal lines below the carpus occurred by 229 days of age in the filly, but these closure times varied in the colt.

9. All of the epiphyseal lines below the carpus were fused by the end of the ninth month.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to all the members of the veterinary staff who helped in many ways with this project.

The author is particularly indebted to Dr. M. A. Emmerson for his radiographic advice and assistance, and for his help in preparing this paper throughout and to Dr. B. W. Kingrey, who gave encouragement and assistance in numerous ways. Dr. Emmerson is also thanked for organizing this project as well as for his early technical work.

Dr. L. R. Hutchinson and Dr. H. Nelson are thanked for their early technical work on this project.

The assistance given by many students with this project was greatly appreciated.

Lou Facto and Dan Hillmann are thanked for their help in preparing the figures used in this paper.

The author is indebted to his wife, Helena, not only for her assistance in the early preparation of this draft, but for her patience and understanding throughout the course of this endeavor.

LITERATURE CITED

1. Adams, O. R. Lameness in horses. Philadelphia, Pa., Lea and Febiger. 1962.

2. Andersen, A. C. and Floyd, M. Growth and development of the femur in the beagle. American Journal of Veterinary Research 24: 348-351. 1963.

3. Bassett, C. A. L. Current concepts of bone formation. The Journal of Bone and Joint Surgery 44-A: 1217-1244. 1962.

4. Bloom, W. and Bloom, M. A. Calcification and ossification calcification of developing bones in embryonic and newborn rats. Anatomical Record 78: 497-524. 1940.

5. ________ and Fawcett, D. W. A textbook of histology. 8th ed. Philadelphia, Pa., W. B. Saunders Company. 1962.

6. Bressou, C., Pomriaskinsky-Kobozieff, N. A., and Kobozieff, N. Étude radiologique de l'aspect du squelette normal de la main du chien. Recueil de Médecine Vétérinaire 133: 449-464. 1957.

7. ________, ________, and ________. Étude radiologique de l'ossification de squelette du pied du chat aux divers stades de son evolution, de la naissance à l'âge adulte. Recueil de Médecine Vétérinaire 135: 611-626. 1959.

8. ________, ________, and ________. Etude radiologique de l'ossification du squellette de la main du chat aux divers stades de son évolution, de la naissance à l'âge adulte. Recueil de Médecine Vétérinaire 135: 547-564. 1959.

9. Carlson, W. D. Veterinary Radiology. Philadelphia, Pa., Lea and Febiger. 1961.

10. Dawson, A. B. Further studies on epiphyseal union in the skeleton of the rat. Anatomical Record 60: 83-86. 1934.

11. ________. The age order of epiphyseal union in the long bones of the albino rat. Anatomical Record 31: 1018. 1925.

12. Ellenberger, W. and Baum, H. Handbuch der Vergleichenden Anatomie der Haustiere. 18. Auflage. Berlin, Germany, Springer-Verlag. 1943.

13. Emara, M. Some observations on epiphyseal union of long bones in young Egyptian cattle and its importance as an aid in the estimation of age. Veterinary Record 49: 1534-1537. 1937.

14. Enlow, D. H. A study of the post-natal growth and remodeling of bone. American Journal of Anatomy 110: 79-102. 1962.

15. Ewart, J. C. The development of the skeleton of the limbs of the horse, with observations on polydactyly. Journal of Anatomy and Physiology 28, New Series 8: 236-256. 1894.

16. ________. The development of the skeleton of the limbs of the horse, with observations on polydactyly. Journal of Anatomy and Physiology 28, New Series 8, part 2: 342-369. 1894.

17. Flecker, H. Roentgenographic observations of the times of appearance of epiphyses and their fusion with the diaphyses. Journal of Anatomy 67: 118-164. 1932.

18. ________. Time of appearance and fusion of ossification centers as observed by roentgenographic methods. American Journal of Roentgenology and Radium Therapy 47: 97-159. 1942.

19. Francis, C. C., Werle, P. P. and Behm, A. Appearance of centers of ossification from birth to five years. American Journal of Physical Anthropology 24: 273-299. 1939.

20. Greulich, W. W. and Pyle, S. I. Radiographic atlas of skeletal development of the hand and wrist. 2nd ed. Stanford, Calif., Stanford University Press. 1959.

21. Habel, R. E., Barrett, R. B., Diesem, C. D. and Roenigk, W. J. Nomenclature for radiologic anatomy. Journal of the American Veterinary Medical Association 142: 38-41. 1963.

22. Ham, A. W. and Leeson, T. S. Histology. 4th ed. Philadelphia, Pa., J. B. Lippincott Company. 1961.

23. Hanlon, G. F. Skeletal maturation and abnormal bone growth in the dog. The Minnesota Veterinarian 3: 6-9. 1963.

24. Hare, W. C. D. Radiographic anatomy of the canine pectoral limb Part 2. Developing limb. Journal of the American Veterinary Medical Association 135: 305-310. 1959.

25. ________. The age at which epiphyseal union takes place in the limb bones of the dog. Wiener Tierärztliche Monatsschrift 9/72: 224-245. 1960.

26. Hill, A. H. Fetal age assessment by centers of ossification. American Journal of Physical Anthropology 24: 251-272. 1939.

27. Hoerr, N. L., Pyle, S. I. and Francis, C. C. Radiographic atlas of skeletal development of the foot and ankle. Springfield, Ill., Charles C. Thomas. 1962.

28. Ingalls, T. H. Epiphyseal growth: normal sequence of events at the epiphyseal plate. Endocrinology 29: 710-719. 1941.

29. Kanan, C. V. Some observations on ossification of the bones of the appendicular skeleton of Camelus dromedarius. Acta morphologica neerlando-scandinavica 4: 254-260. 1961.

30. Koch, W. The age order of epiphyseal union in the skeleton of the European bison (Bos bonasus L.). Anatomical Record 61: 371-376. 1935.

31. Küpfer, M. Beiträge zum Modus der Ossifikationsvorgänge in der Anlage des Extremitätenskelettes bei den Equiden der Verknöcherungsprozess in der Pferde- und Eselgliedmasse auf Grund Röntgenologischer Untersuchungen. Denkschriften der Schweizerischen Naturforschenden Gesellschaft Mémoires de la Société Helvétique des Sciences Naturelles 67, No. 67: 1-352. 1931.

32. Lesbre, M. F.-X. Contribution a l'etude de l'ossification du squellette des mammifères domestiques principalement aux points de vue de sa marche et de sa chronologie. Annales de la Société d'Agriculture Sciences et Industrie de Lyon 5, 7 serie. 1897.

33. Menees, T. O. and Holly, L. E. The ossification in the extremities of the new-born. American Journal of Roentgenology and Radium Therapy 28: 389-390. 1932.

34. Nissen, H. W. and Riesen, A. H. Onset of ossification in the epiphyses and short bones of the extremities in chimpanzees. Growth 13: 45-70. 1949.

35. Patten, B. M. Foundations of embryology. New York, N. Y., McGraw-Hill Book Co., Inc. 1958.

36. Pomriaskinsky-Kobezieff, N. and Kobezieff, N. Étude radiologique de l'aspect du squelette, normal de la main du chien aux divers stades de son évolution de la naissance à l'âge adulte (1). Recueil de Médecine Vétérinaire 130: 617-646. 1954.

37. Pryor, J. W. Differences in the time of development of centers of ossification in the male and female skeleton. Anatomical Record 25: 252-273. 1923.

38. ________. Time of ossification of the bones of the hand of the male and female, and union of the epiphyses with the diaphyses. American Journal of Physical Anthropology 8: 401-410. 1925.

39. Pyle, S. I. and Hoerr, N. L. Radiographic atlas of skeletal development of the knee. Springfield, Ill., Charles C. Thomas. 1955.

40. ________, Stuart, H. C., Cornoni, J., and Reed, R. B. Onsets, completions, and spans of the osseous stage of development in representative bone growth centers of the extremities. Monographs of the Society for Research in Child Development 26, No. 1: 1-126. 1961.

41. Retterer, E. Contribution au développement du squelette des extrémités chez les mammifères. Journal de l'anatomie et de Physiologie Normales et Pathologiques de l'Hommes et des Animaux 20: 467-614. 1884.

42. Rooney, J. R. Normal bone structure. In Bone, Catcott, Gabel, Johnson and Riley, eds. Equine Medicine and Surgery. pp. 407-409. Wheaton, Ill., American Veterinary Publications, Inc. 1963.

43. Rosenberg, A. Ueber die Entwicklung des Extremitätenskeletes bei einigen durch Reductionen ibrer Gliedmassen characterisirten Wirbelthieren. Zeitschrift für Wissenschaftliche Zoologie 23: 116-170. 1873.

44. Roshdesstwenskaja, G. Wachstum und Entwicklung der Extremitäten bei Fohlen im ersten Lebensjahr. Pferdezucht u. Pferdesport 30 (105): 30-32. 1960. Original not available for examination; abstracted in Landwirtschaftliches Zentralblatt der Deutschen Akademie der Landwirtschaftswissenschaften zu Berlin Abteilung 4 Veterinarmedizin 6: 1311. 1961.

45. Rozhdestvenskaya, G. A. Bone formation in limb bones of foals during the first year of life. Trudy Vsesoyznznyi nauchno-issledovatel' skii Institut Konevodstva 23: 321-330. 1960. Original not available for examination; cited in Index Veterinarius 29 No. 4: 21. 1961.

46. Saarni, I. Die Intrauterine Entwicklung der Extremitätenknochen des Pferdes. Inaugural-Dissertation. Giessen, Germany. 1921.

47. Schlotthauer, C. F. and Janes, J. M. The time of closure of the lower femoral epiphyses and upper tibial epiphyses in the dog as determined by roentgenogram. American Journal of Veterinary Research 13: 90. 1952.

48. Schmidt, G. Epiphysen und Apophysen in der Röntgenologischen Darstėllung in den Vorder-und Hinterextremitäten der Fohlen. Inaugural-Dissertation. Hannover, Germany. 1960.

49. Seoudi, R. X-Ray examination of epiphyseal union as an aid to the estimation of the age in dogs. British Veterinary Journal 104: 150-155. 1948.

50. Siegling, J. A. Growth of the epiphyses. Journal of Bone and Joint Surgery 23: 23-36. 1941.

51. Sisson, S. A text-book of veterinary anatomy. 1st ed. Philadelphia, Pa., W. B. Saunders Company. 1910.

52. ________ and Grossman, J. D. The anatomy of the domestic animals. 4th ed. Philadelphia, Pa., W. B. Saunders Company. 1956.

53. Smith, R. N. Fusion of the epiphyses of the limb bones of the sheep. The Veterinary Record 68: 257-259. 1956.

54. ________. Radiological observations on the limbs of young greyhounds. The Journal of Small Animal Practice. 1, No. 2: 84-90. 1960.

55. ________ and Allcock, J. Epiphysial fusion in the greyhound. The Veterinary Record 72, No. 5: 75-79. 1960.

56. Spark, C. and Dawson, A. B. The order and time of appearance of centers of ossification in the fore and hind limbs of the albino rat, with special reference to the possible influence of the sex factor. American Journal of Anatomy 41: 411-445. 1928.

57. Stevenson, P. H. Age order of epiphyseal union in man. American Journal of Physical Anthropology 7: 53-93. 1924.

58. Stoss, A. O. Tierärztliche Geburtskunde und Gynäkologie einschliesslich der Krankleiten der Neugeborenen. Stuttgart, Germany, Ferdinand Enke. 1928.

59. Struthers, J. On the development of the bones of the foot of the horse, and of digital bones generally; and on a case of polydactyly in the horse. Journal of Anatomy and Physiology 28, New Series 8: 51-62. 1893-1894.

60. Todd, T. W. and Todd, A. W. The epiphyseal union pattern of the ungulates with a note on sirenia. American Journal of Anatomy 63: 1-36. 1938.

61. Tohara, S. Radiographical studies on the ossification of leg-bones of horses. Japanese Journal of Veterinary Science 12, No. 1: 1-12. 1950. Original available but not translated; English summary used.

62. Trautmann, A. and Fiebiger, J. Fundamentals of the histology of domestic animals. Ithaca, N. Y., Comstock Publishing Associates. 1957.

63. Van Wagnener, G. and Asling, C. E. Roentgenographic estimation of bone age in the rhesus monkey (Macaca mulatta). American Journal of Anatomy 103: 163-185. 1958.

64. Walker, D. G. and Wirtschafter, Z. T. The genesis of the rat skeleton a laboratory atlas. Springfield, Ill., Charles C. Thomas. 1957.

65. Washburn, S. L. The sequence of epiphyseal union in old world monkeys. American Journal of Anatomy 72: 339-360. 1943.

66. Zietzschmann, O. and Krölling, O. Lehrbuch der Entwicklungschichte der Haustiere. Berlin, Germany, Paul Parey. 1955.

67. Zuck, T. T. The age order of epiphyseal union in the guinea pig. Anatomical Record 70: 389-399. 1938.