

Growth and Development of the Normal Canine Pelvis, Hip Joints and Femurs from Birth to Maturity: A Radiographic Study¹

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INTRODUCTION

This is a radiographic, gross and microscopic study of normal hip development from birth to maturity in the Greyhound. A clear understanding of the normal development pattern is imperative as a rational basis for comparison in evaluating radiographic changes associated with disease and injury of the hip.

LITERATURE REVIEW

There is a scarcity of reports dealing with the detailed prenatal development of the hip. The most thorough investigation describes how the limb buds are composed of mesoderm and appear as small protrusions on the lateral sides of the newly formed spine (12). This work stresses that it is possible for all parts of the hip to form within the joint enclosure from the designated primordia. Development of the hip proceeds normally as long as the structures differentiate within the range of balanced neutral forces and allow the acetabulum and femoral head to remain in full congruity (12).

More attention has been given to the development of joints and limbs after birth (14). In discussions of the canine skeleton, the Greyhound was the breed studied most frequently (2, 10, 11).

The anatomy of the adult dog has been described. The most extensive details are available in a recent American text (5).

MATERIALS AND METHODS

Four female purebred Greyhounds were studied. A 1-year-old male Greyhound was also included to complete the data on growth and development from birth to maturity.³ The parent stock was retired from racing. The bitch whelped in our kennel. The pups were weaned at 30 days of age.

Four females from one litter were chosen for serial radiographs of the pelvis. Females were selected rather than males to avoid having the os penis interfere with the radiographic image of the pelvis. The pups were subjected to short caudectomies at birth for the same reason. One was designated at random for serial radiographic study. The other three served as controls for comparing weight, size and growth, and for replacement if the one being radiographed became ill or her development varied from the three controls. They were kept with the mother until weaning. The four females were then penned together away from the remainder of the litter.

Starting at the day of birth, radiographs were taken of the pelvis and femurs of the

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³None of the Greyhounds used in this study received training for racing, but all Greyhounds were from racing stock.

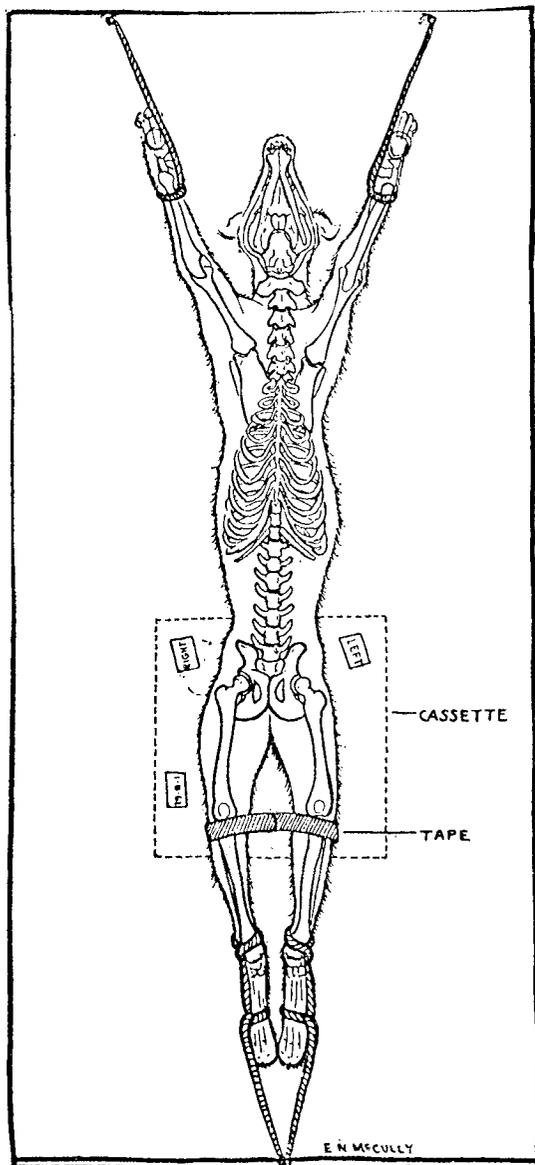


Fig. 1. Drawing of a dog secured in the extended ventrodorsal position for radiography of the pelvis. (This figure published with permission of The American Animal Hospital Association).

selected dog twice daily (morning and evening) for the first 4 weeks of life, then daily for the next 26 weeks until the dog was 30 weeks old (seven months). At seven months, 95% of the growth in bone length was completed. A 1-year-old male Greyhound was included for comparison and to complete the data on the growth pattern of the pelvis and femurs.

Radiographs of the pelvis and femurs

were taken with the hind legs extended to the maximum as described previously (4). In this position the pelvis and femurs were parallel to the long axis of the body and relatively close to the cassette when radiographed, thus minimizing bone magnification and distortion (Fig. 1).

The dogs were weighed at weekly intervals from birth to maturity at 40 weeks, after which they were euthanized.⁴ The 1-year-old male Greyhound was also weighed and radiographed.

There were no significant differences in the growth rate, size, shape and weight of the four females (the one radiographed and the three controls).⁵ At 10 weeks of age, however, the dog being radiographed developed an acute respiratory illness and was euthanized. She was replaced by a sibling. When the illness was noticed, the dog and her replacement were the same size and the pelvic radiographs were indistinguishable. The sibling was in good health and grew normally during the entire experiment. It is believed that the data obtained from these dogs represents an average normal growth, weight and size pattern for the Greyhound breed, and that the bone and body size of the male and female of this breed varied insignificantly (males 26 to 30 kg, females 23 to 27 kg). References to mean measurements for size and weight of this breed were not found.

Tracings of serial radiographs of the pelvis, femurs and hip joints were made to determine the changes in size and form during the growth period.

Weight Gain

The dogs made a steady weight gain from birth through the growth period (Fig. 2). A standard dry kennel food⁶ was fed *ad lib* from the time the dogs began eating

⁴ One dog died at 10 weeks of age.

⁵ The Section of Radiobiology, Armed Forces Institute of Pathology, reported the amount of X-radiation exposure was well below the dose required to retard the rate of bone growth in the young dog.

⁶ Ralston Purina Dog Meal, Ralston Purina Company, St. Louis, Mo.

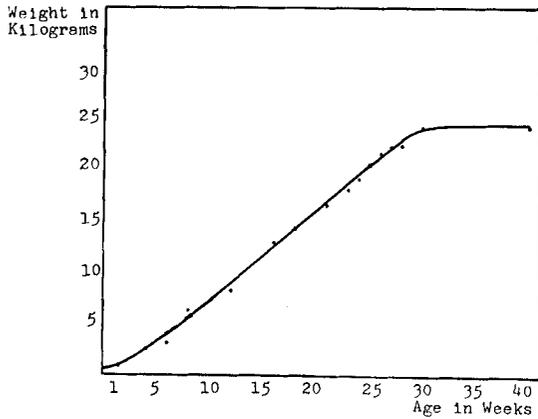


Fig. 2. Weight chart of the Greyhound dogs in kilograms per week.

until they were euthanized. The growth curve increased steadily for the first 28 weeks of life after which it leveled or straightened. The rise of the curve was the greatest between the 10th and 28th weeks. After the 28th week, the weight in the three remaining dogs was constant until they were euthanized at 40 weeks (Fig. 2). The weight recorded on the chart at each date was a mean weight of the four dogs for the first 10 weeks and for the three remaining dogs for the remainder of the experiment. The dogs were in good health and ate well during the experiment except for the illness of the one. The mean weight obtained was 22 kg when the weight

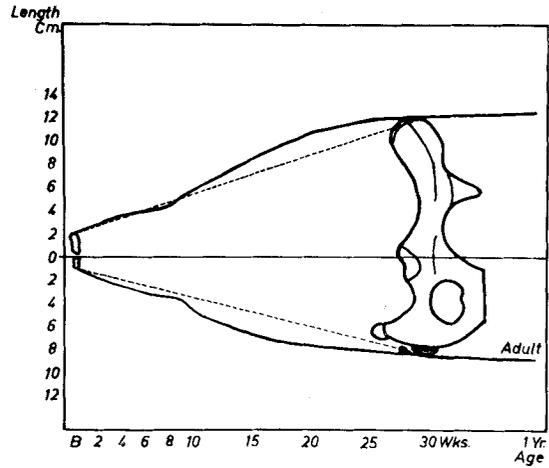


Fig. 4. Chart drawn from radiograph overlay tracings of one-half of the pelvis of a dog at intervals from birth to one year of age. The bipolar growth plate between the ilium and ischium served as the center point of growth. B refers to size at birth.

curve leveled by the 31st week. This represented approximately 90% of the total normal weight for the average adult female Greyhound. The growth in weight followed and correlated well with the increase in size of the femur and pelvis over the same period (Figs. 2-4). These increases were consistent for all dogs. The surviving dog that was radiographed and the two controls stayed in the same weight range.

Longitudinal Growth of the Femur

The nutrient artery around which the bony nutrient foramen later forms is at the center point of a long bone when the cartilage mold is laid down in the skeleton of the fetus (5, 6). By identifying the nutrient artery it is possible to measure the growth at the two ends of a long bone. At birth it is difficult to measure the length of a long bone radiographically because only the diaphysis between the proximal and distal physes (growth plates)⁷ is radiopaque. The cartilagenous epiphyses are radiolucent.

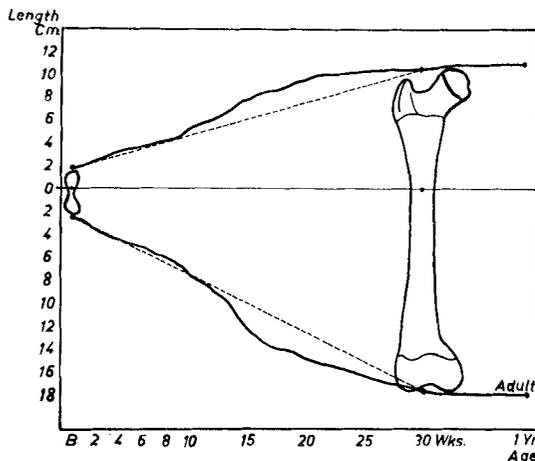


Fig. 3. Chart drawn from radiograph overlay tracings of the femur at intervals from birth to one year of age. The "O" point on the vertical axis is the level of the nutrient foramen.

⁷ The lucent line seen radiographically between the epiphysis and metaphysis is known as the physis.

In this study, at 12 days of age, the proximal and distal epiphyses were ossified sufficiently to be radiopaque. At 6 weeks the nutrient foramen was identified. In retrospect, with these landmarks, it was possible to identify the position of the nutrient foramen and the ends of the bone on the radiographs taken previously following birth.

At birth, the estimated total length of the femur was 3.5 cm with 1.5 cm proximal to the nutrient foramen and 2 cm distal to it. The femur maintained a uniform weekly length increase (Fig. 3). When the measurements were charted, the weekly growth as indicated on the chart for the proximal portion maintained an increase at a slope of approximately 20° until growth slowed at the 30th week. Between the 10th and 30th weeks the slope increased from approximately 25° to 30°. The distal portion of the femur grew faster. Its growth rate was at a slope of approximately 50°. A 1:1.5 growth ratio was maintained between the proximal and distal portions of the femur from birth to adulthood.

At 30 weeks of age the over-all length of the femur was 23.5 cm with 9.5 cm proximal to the nutrient foramen and 14 cm distal to it. This length represented 95% of the total adult femoral length and was within 0.9 cm of the length of the femur of the 1-year-old 26-kg male Greyhound whose femur measured 24.4 cm with 9.9 cm proximal and 14.5 cm distal to the nutrient foramen (a ratio of 1:1.5).

Shape of the Femur

At birth, only the metaphyses and diaphyses of the femurs were visible radiographically and these were of hour-glass shape (Figs. 3, 5). The distal end was slightly larger in length and width than the proximal one. The ossification of the head (proximal epiphysis) and distal condylar epiphysis was sufficient to be visible at 12 days of age, and the shape of the head and condyles was evident by the 13th day.

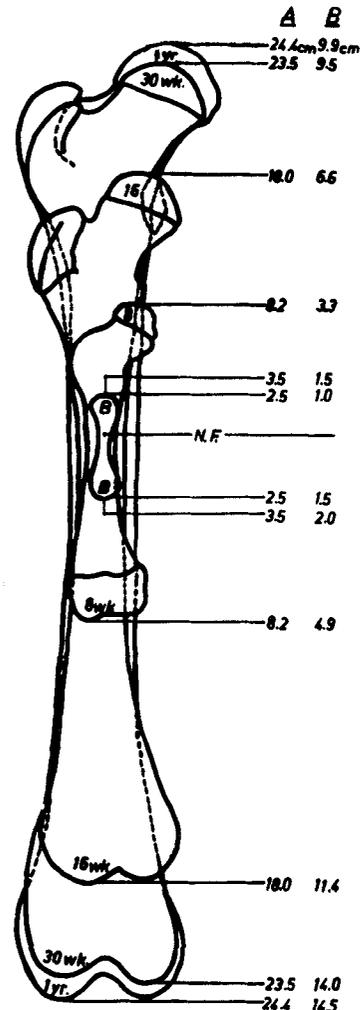


Fig. 5. Chart drawn from radiograph overlay tracings of a femur from birth to one year of age. The nutrient foramen (NF) served as the center point of growth from which measurements were made. (A) Total length of femur at the specified ages. (B) Length of proximal and distal ends of femur from the nutrient foramen (NF) at the specified ages.

Radiographically the center of ossification for the femoral head had the appearance of a small opaque circle after ossification began. By the fourth to fifth week the epiphysis appeared to be attached to the proximal end of the femur except for a thin radiolucent line which was the physis (Fig. 6). The proximal surface of the head was uniformly rounded initially. By the sixth to seventh week a notch appeared on the medial surface of the femoral head where the *ligamentum teres* attaches. The

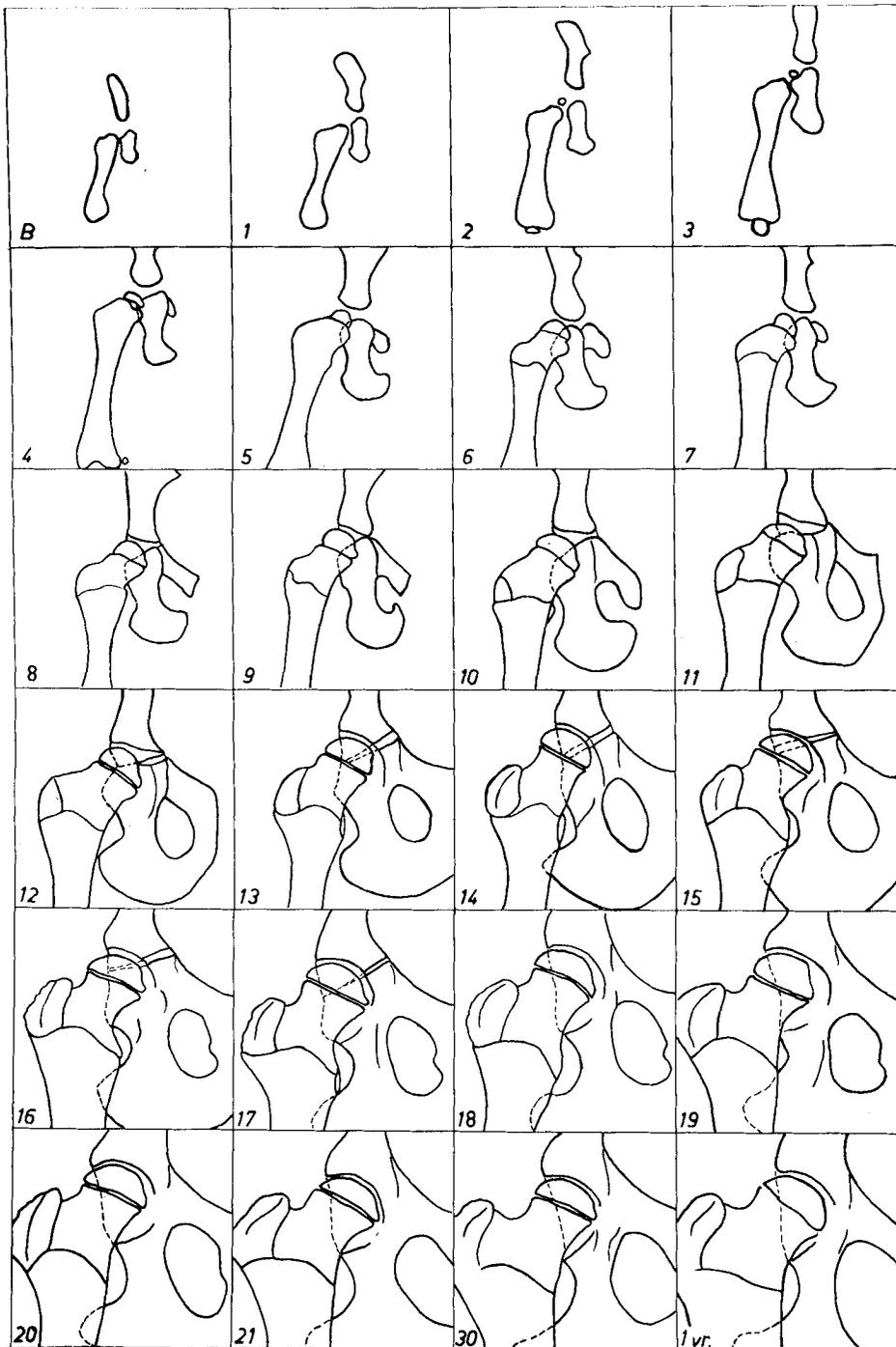


Fig. 6. Drawings copied from radiograph overlay tracings of normal hip joint growth and development from birth to one-year-old. The number with each drawing indicates the age of the dog in weeks.

diameter of the proximal physis was more than twice the height of the proximal epiphysis.

Physes (Growth Plates)

These radiolucent structures are composed of columns of cartilage which lie parallel to the long axis of the femur and the direction of forces (either compression or traction) exerted upon this bone.

The femur has three physes. The two proximal ones once were joined, but separated when the femoral head and greater trochanter moved away from each other as a result of the pulling forces of *gemelli*, the *obturator externus* and the *obturator internus* muscles (3). These physes are distinct and relatively the same width from the time of their appearance when ossification of the head is first visible until 80% of the growth is completed at five months of age. Then the width of the cartilage space narrows gradually. It disappeared radiographically between 11 and 14 months of age (Figs. 3, 5).

The physis at the distal end of the femur is modeled to withstand compression, shear and torsion forces. It has a stud-like surface with four prongs which insert into the epiphysis of the distal condyles. This physis remains active and appears radiolucent until the 10th to 13th month.

Femoral Neck

The diameter of the femoral neck narrows slightly directly below the head. The joint capsule attaches around the neck immediately distal the area where the femoral head unites with the neck. The trochanteric fossa appears as a deep cavity. The angle of the neck with the diaphysis as viewed on the ventrodorsal radiograph in this study was 135°. This neck angle was constant from birth through all ages of development (Figs. 3, 5).

The anteversion angle of the femoral neck⁸ was 0° to 20° with a mean of 10°.

⁸ The anteversion angle is the angular relationship of the long axis of the femoral neck to a line drawn through the femoral condyles in a coronal plane.

It was obtained from the measurements of 32 macerated femurs of 16 mature Greyhounds. A number of other Greyhound pups were also examined from birth to adulthood. The anteversion angle at birth was 0°. It increased gradually with age.

The trochanter and femoral head in the embryological state are composed of a single piece of cartilaginous tissue. With the development and contraction of the muscles of the pelvis, the trochanteric fossa is formed to allow for the insertion of the *obturator internus*, *obturator externus* and *gemelli* muscles (2). The greater trochanter is extended by the dorsal and medial pull of the three pairs of gluteal muscles. In this study the trochanter became visible radiographically between the 8th and 9th weeks of life. The lesser trochanter on the medial side of the femur appeared as an apophysis and was composed of cartilage during the early weeks of life. It became identifiable radiographically at 10 to 12 weeks. When the physes closed (11 to 13 months) this process attached (as a single piece) to the diaphysis of the femur (Fig. 6).

Femoral Shaft

The metaphyses developed and extended proximally and distally as the columns of cartilage cells of the physes matured and disintegrated, new trabeculae ossified and the bones lengthened. Both the length and diameter of the femoral shaft increased in diameter by six to seven times during growth (from 3 to 17.5 mm). The length increased from 3.5 to 24.5 cm (Fig. 5). There was a direct correlation between growth in length and diameter.

Femoral Condyles

The shape of the condyles at the distal end of the femur varied little during growth. The increase in size was in proportion to the remainder of bone.

Growth of the Os Coxae (Innominate Bone)

The innominate bone is united with its contralateral fellow to form the pelvis.

This consists of the ilium, ischium, pubis and acetabular bones. Only portions of

the ilium and ischium were visible radiographically at birth (Fig. 6).

At birth all of the bones are present. The hip joint, with the acetabulum and femur, is functional and stable (Fig. 6). The bones constituting the hip joint are cartilaginous and radiolucent at birth except for portions of the ilium and ischium (Fig. 7).

Longitudinal Growth

Cartilagenous physes unite the ilium, ischium and pubis. These physes are functionally bipolar, *i.e.*, enchondral ossification takes place on both sides of the cartilage strip in the areas which unite the ilium, ischium and pubis. By the 28th week practically all of the enchondral growth of the pelvis has been completed. An additional increase of 2 cm in total length (1 cm at each end) is added as the tuber ilium and tuber ischium are stimulated by traction of the attached muscles (3).

At birth the ilium is approximately one-third longer than the ischium. These two parts maintain a 3:2 growth ratio during the growth period and throughout life. The total weekly size increase of the *os coxae* was uniform during the growth period. When plotted on a graph the ilium growth slope was 30° and the ischium was 20° (Fig. 4). Between the 10th and 30th weeks both slopes increased somewhat until the 29th week, when skeletal growth slowed abruptly. The growth patterns of the *os coxae* and the femurs are almost identical if the upper and lower curves of the *os coxae* are reversed (Figs. 3, 5).

Ilium

This scapula-shaped bone is divided into a wide cranial part known as the wing, and caudal compressed part which forms the cranial half of the acetabulum. Midway on the medial surface is a powerful synarthrosis which unites the pelvis with the sacrum. The growth lines, the shape of the ilium and the angle (slope) at which the ilium is secured to the sacrum vary relatively little from birth to maturity.

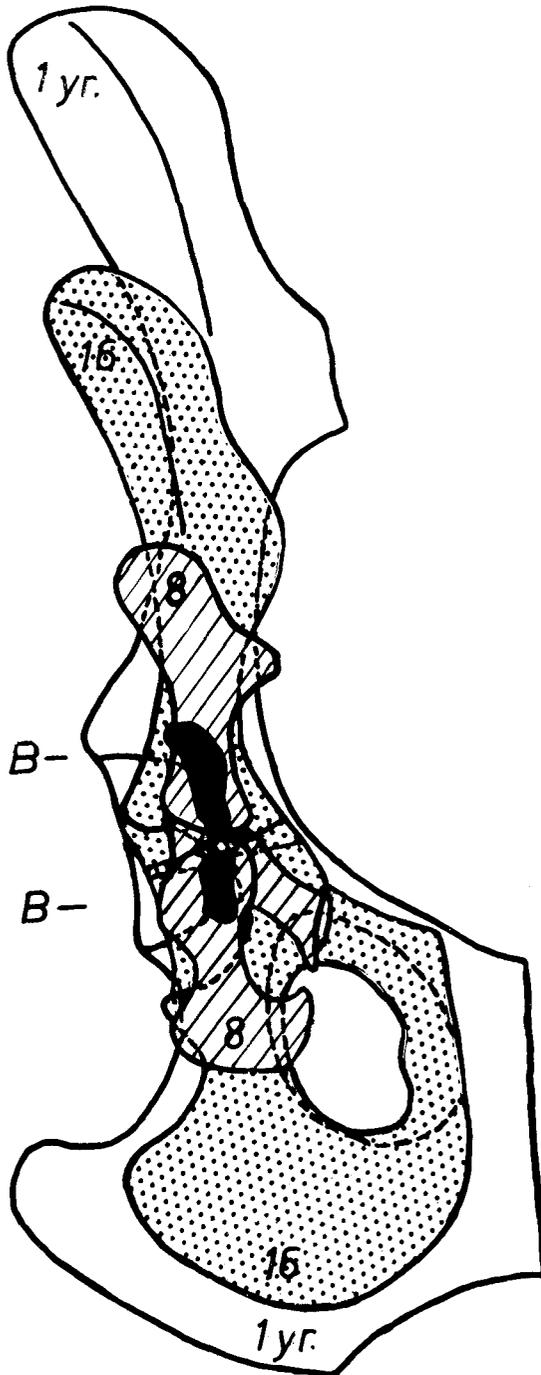


Fig. 7. Chart drawn from overlay tracings of radiographs of one-half of the pelvis of a dog at birth, eight weeks, 16 weeks and one year old. The bipolar growth plate between the ilium and ischium served as the center point of growth.

Ischium

The ischium consists of the body, the sciatic tuberosity with its cartilaginous caudal border, and the curved ramus. These parts are all present at birth, but only a small rectangular piece of the ischial body is visible radiographically. The shape of the ischial body and ramus became visible rapidly within the next 20 days. Even by the first week the body had lengthened and the caudal end had become paddle-shaped and hooked as the tuberosity and ramus continued to ossify. The obturator foramen became evident when the pubis and ischium ossified at the seventh week.

Pubis

The pubis appeared radiographically at the fourth week and could be identified with its contralateral mate by the ninth week. The pubic symphysis and obturator foramen were visible by the 11th week (Fig. 6).

Acetabulum

The acetabulum is a cotyloid lunate cavity created by the fusion of the ends of three bones: ilium, ischium, pubis. These encircle a fourth bone, the acetabular bone. The articular surface of the acetabular cavity is horseshoe-shaped and open ventrally. There is a central acetabular fossa. It is estimated that the ilium and ischium each contribute two-fifths of the acetabulum and the pubis and acetabular bone together contribute one-fifth.

Radiographically the union of these bones was masked by the head of the femur and could not be distinguished until the 12th week when the acetabular cavity had ossified sufficiently to give an adequate radiographic image (Fig. 6). A Y-shaped strip of endochondral cartilage united the ilium and ischium at the dorsal rim of the acetabulum. This was the last area to ossify. A secondary center of ossification located on the craniodorsal acetabular rim was visible sometimes on ventrodorsal pelvic radiographs of dogs between the 11th and 14th weeks of age (Fig. 4).

Relationship of the Femoral Head and Acetabulum

When the head was first recognized as a radiopaque dot at 12 days, it was positioned well within the visible bony boundaries of the acetabular cavity. As the bones of the cavity and head mineralized sufficiently to be recognized, approximately two-thirds of the globe of the femoral head lay within the acetabular cavity. This relationship did not change as the area ossified. As ossification progressed, the radiolucent non-ossified cartilaginous spaces narrowed (Fig. 6).

Gross and Histological Development of the Normal Hip

The hip joints of all dogs are normal at birth (6, 7). The joints continue to develop normally as long as full congruity is maintained between the acetabulums and femoral heads (12).

The most valuable insight into the appearance of the normal hip was gained by following the development of the coronal profile by the use of histologic sections taken through the proximal femoral shaft and heads and acetabulum of the intact hip joint. Figure 8 is a photograph of six normal hip joints. The first is from a dog 12 days of age, a time when the epiphyseal ossification begins. The others illustrate various stages of development at 4 weeks, 8 weeks, 16 weeks, 24 weeks and finally the hip from a dog over two years of age.

In these six photographs the dominant feature is the display of balance, symmetry and grace in each joint. Each evidences the same angles of balanced cantilever support for the body weight through the dorsal curvature of the acetabulum and onto the femoral head and shaft, with lines of force converging into the medial femoral cortex.

The trabeculae present in the acetabulum and femoral head and neck serve as a series of radiating "studs" and "braces" arranged in linear fashion as dictated by compression and tensile stresses.

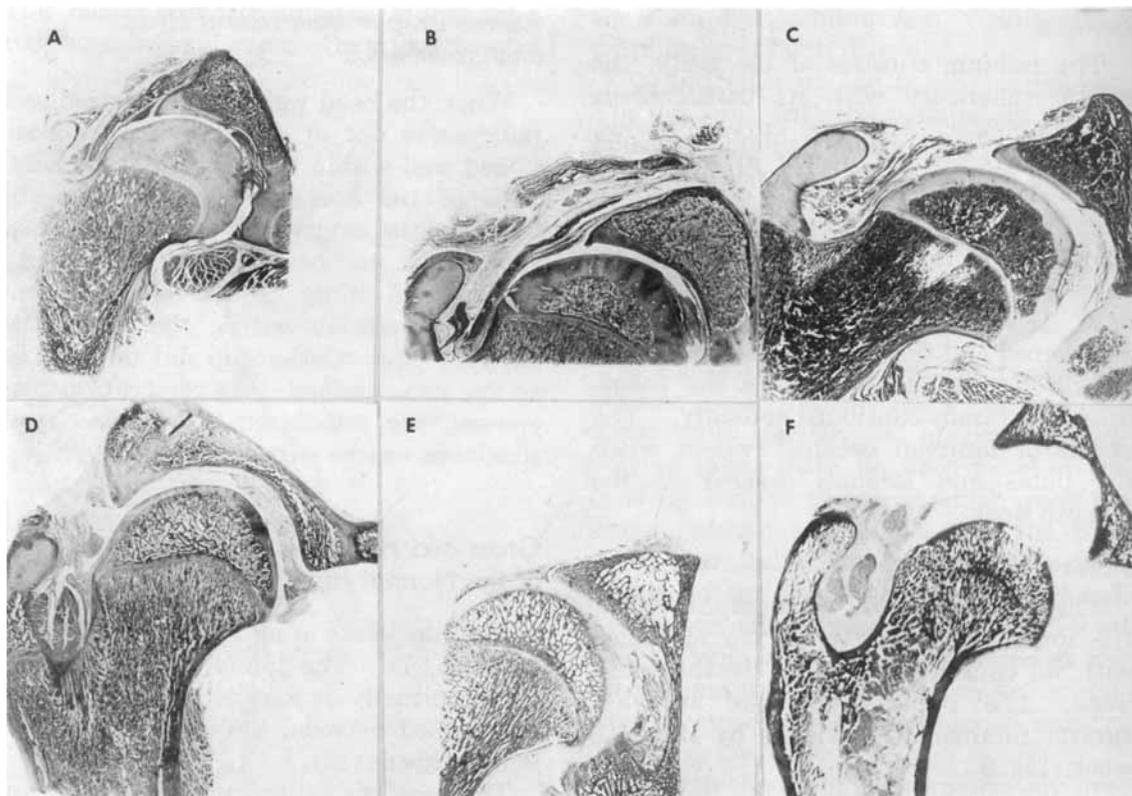


Fig. 8. Coronal histological preparations of normal hips of dogs, (A) 12 days, (B) four weeks, (C) eight weeks, (D) 16 weeks, (E) 24 weeks and (F) two years. These illustrate the normal development and maintenance of the hip joint. At all stages of development and maturity there is an achievement of functional balance, symmetry and congruity between the femoral head and the acetabular cavity. (Excessive separations between the femoral heads and acetabula are preparation defects.) The entire articular surface of the acetabulum and femoral head are maintained in full congruity with each other while in a full range of motion. The body weight is distributed evenly over the contacting articular surfaces. The hip joint functions with the forces about the hip neutralized and balanced. In these illustrations there is no evidence of abnormal development, remodelling or wear.

In all six illustrations there is symmetry and grace in the outline of the bones. The supporting trabeculae are distributed evenly. The increase in size with growth is uniform and orderly. No overgrowth of bone occurs and the cortices are thin. Such joints have functioned within the parameters of neutral forces.

The effects of balanced forces are well illustrated in the hip joint section of the two-year-old racing Greyhound (Fig. 8F). In spite of the extensive training and hard work of this dog, the hip joint shows no evidence of wear, hypertrophic ossification or deformation remodeling. In this hip the same lines of design exist after extensive abuse that are seen in the 12-day-old dog (Fig. 8). Histologically, the bones composing the acetabular fossa are thin

with a minimum of trabecular bone (Fig. 8). The dorsal portion of the acetabular cavity is extended sufficiently to cover two-thirds of the femoral head (Fig. 8). The cortices and trabeculae of the dorsal rim are thin. The acetabular rim (beak) is sharp and pointed (Fig. 8F).

Histologically, the proximal end of the femur and trochanter appear almost osteoporotic. There is very little bone at the subchondral plate beneath the articulating surface of the femoral head and an absence of extra bone beneath the attachment of the teres ligament. The trabeculae supporting the femoral head are few and thin in diameter, but they form a triangle converging into the medial cortex (Fig. 8F). The medial cortex is dense and thin indicating that stress forces are minimal. In the

trochanteric fossa, the site where the *gemelli*, *obturator externus* and *obturator internus* muscle insert, the trabecular response is minimal, indicating that the hip was balanced sufficiently so there were no unusual forces on these attachments. In the trochanter major there is also a scarcity of both cortical and trabecular bone. The cortex is slightly thicker at the dorsal rounded tip of the trochanter and at the point where the trochanter joins the femur. These are the sites of attachment for the three gluteal muscles (Fig. 8F).

The long axis of the diaphysis and the neck form an angle of nearly 135°. The graceful structure of the joint and adjacent bones reflects neutral stresses (compression, tension and torsion), sufficient lubrication and balanced muscle pull upon all of the bony components in the joint.

In Figure 8 the acetabular rims (beaks) are stimulated to grow by mild traction applied by the joint capsule and gluteal muscles attached along their dorsal borders, and from pressure by the femoral heads upon the articular surfaces. The diameters of the acetabular cavities are only slightly larger than the femoral heads.

DISCUSSION

A normal hip must be an example of symmetry, grace and balance as it develops and maintains itself from birth through adulthood. The hip joint is composed of specialized tissues all of which participate in a programmed chain of development (13). Except for the racing and toy dog types, there is a great chance that the canine hip will develop abnormally (9).

The morphologic characteristics of the complex hip structure leave no serious question that biomechanical behavior is the prime influence in the growth of this joint (3). The display of symmetry, grace and balance in the femoral head and neck, the trochanter and the acetabulum of the normal hip is impressive when coronal histological sections are studied. The six photographs of this joint representing all ages from shortly after birth to late maturity

depict how these qualities are maintained (Fig. 8). The photograph of a highly-trained racing dog retired after more than two years of grueling work displays no evidence of joint instability, wear, remodeling or degeneration (Fig. 8F).

The laws that control bone and soft tissue dynamics control the development of the hip. What are these laws? Newton's law of neutral forces when applied to biological tissues means that a joint is in functional equilibrium when all forces upon that joint mutually neutralize each other both in intensity and direction. Wolff's law introduces the concept of bone transformation in that changes in function of a bone are attended by alterations in its internal structure. It applies to cancellous and cortical bone (1).

In all six coronal sections of the hip (Fig. 8) there is no overgrowth of bone and the cortices are thin. Such joints are functioning within the parameters of neutral forces. There is no evidence of unbalanced forces having caused alterations in the cancellous or cortical structures of the bones making up the hip.

It has been stated previously that the hip joints of all dogs are normal at birth (6-9). They continue to develop normally as long as full congruity is maintained between the acetabula and femoral heads (12). If the joint components are pulled apart, development follows an abnormal course which correlates with the degree of incongruity (9). The biomechanical balance necessary for development of normal hips is demonstrated in this report.

SUMMARY

The body growth rate and weight gain, femoral shape and length, *os coxae* shape and length and shape of the normal hip joint as seen in the Greyhound have been recorded from birth to maturity. The relationship of the femoral head to the acetabulum is appraised radiographically. Since the growth of the pelvic skeleton of the Greyhound closely resembles the normal

radiographic appearance of the hip joints of many large and giant breeds, it provides a basis for comparison with abnormal hips.

The development of the normal hip is followed from birth to two years in histological coronal profile sections made through the proximal femur and acetabulum. The sections were taken from dogs at 12 days, 4 weeks, 8 weeks, 16 weeks, 24 weeks and 2 years of age. In all stages of development and maturity there is an achievement of functional biomechanical balance, symmetry and congruity between the femoral head and acetabulum.

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ZUSAMMENFASSUNG

Die Körperwachstumsrate und Gewichtzunahme, die femorale Form und Länge, die *os coxae* Form, un Länge und Form des normalen Hüftgelenkes, wie sie beim Windhund gesehen werden, sind von Geburt bis zur Reife aufgezeichnet worden. Das Verhältnis des femoralen Kopfes zur Gelenkpfanne wird radiographisch ausgewertet. Da das Wachstum des Beckenskelettes des Windhundes sehr stark der normalen radiographischen Erscheinung der Hüftgelenke vieler grosser und Riesenzüchtungen ähnelt, ergibt es eine Basis für einen Vergleich mit abnormalen Hüften. Die Entwicklung der normalen Hüfte wird verfolgt von der Geburt bis zu zwei Jahren in histologischen Kronenprofilschnitten, die durch den obersten Teil des Femurs und der Gelenkpfanne gemacht wurden. Die Schnitte wurden entnommen von Hunden von 12 Tagen, vier Wochen, acht Wochen, 16 Wochen, 24 Wochen und zwei Jahren Alter. Bei allen Stadien von Entwicklung und Reife gibt es die Erreichung von einem funktionellen, bio-mechanischen Gleichgewicht, Symmetrie und Kongruität zwischen dem femoralen Kopf und der Gelenkpfanne.

RÉSUMÉ

On a enregistré chez le lévrier, de sa naissance à sa maturité le taux de croissance du corps et le gain de poids, la forme et la taille du fémur, la forme et la taille de l'*os coxa* ainsi que la forme et la taille de l'articulation normale de la hanche. On a évalué radiographiquement la relation de la tête fémorale par rapport à l'acétabule. Etant donné que la croissance de l'ossature pelvienne du lévrier ressemble particulièrement à l'aspect normal radiographique des articulations de hanche de maintes races d'animaux de grande taille ou géants, cela nous fournit une base pour procéder à la comparaison avec des articulations anormales.

On a suivi de près, de la naissance à l'âge de deux ans le développement de l'articulation normale dans des sections de profil coronal histologique faites d'un bout à l'autre du fémur et de l'acétabule. Les sections ont été prises sur des chiens à l'âge de douze jours, quatre semaines, huit semaines, seize semaines, vingtquatre semaines et deux ans. A tous les stades de développement et de maturité il se produit un équilibre biomécanique fonctionnel, une symétrie et une congruence entre la tête fémorale et l'acétabule.