Distal Ulnectomy in Young Dogs

Affect on

Forelimb Growth and Carpal Stability

by

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Introduction

Normal growth and development of the canine antebrachium is a function of the growth plates (physes) of the radius and ulna, and the ability to maintain the normal alteration in relationship between the radius and ulna as they grow and lengthen. Growth of the canine radius originates from the proximal and distal physes, as does growth of the ulna (Fig. 1). Longitudinal growth of the ulna from the elbow joint distally occurs from the distal ulnar physis, therefore, for normal growth of the antebrachium the distal ulnar physis must grow at a rate equal to both radial physes combined. Alteration in the relationship between the radius and ulna must occur to insure a constant relationship between the proximal articular surface of the radius and adjacent articular surface of the coronoid process and trochlear notch of the ulna.[29]

The distal ulnar physis is conical in shape, seemingly unique to the dog, and due to its conformation is unable to shear regardless of the shearing, lateral or axial forces placed on the forelimb.[40] Therefore, any shearing force applied to the distal ulnar physis results in damage to the germinal cells of the physis due to the apex of the metaphysis being driven down into the epiphysis causing compression of one side of the conical physis. If damage is severe enough, premature cessation of growth occurs.[30,39,40]

Forelimb deformity secondary to early closure of the distal ulnar physis is the most common complication of physeal injury in the dog.[4,5,10,17,31,40] Premature retardation or closure of the physis results in decreased or cessation of ulnar growth. The ulna then acts as a retarding strap twisted around the radius which as it continues to grow must bow away from the ulna. The retarding action of the ulna on the radius results in a number of growth deformities including anterior curvature of the radius, lateral deviation of the foot, subluxation of the humeroulnar joint, outward rotation of the distal antebrachium and pes, and posterior subluxation of the carpus. Abnormal articulation in the elbow and/or carpus results in irreversible degenerative osteoarthrosis (Fig. 2).[1,6,29,31]

The syndrome, commonly termed "radius curvus", has been described clinically,[17,30,31,35,37,40] and produced experimentally by stapling[10,16,17] and by irradiation of the distal ulnar physis.[4,5,6] The radiographic changes associated with distal ulnar retardation have been described, as well as the associated changes occurring in the elbow joint.[4,5,6,17,31,35,37]

This report is divided into two groups of study. The first study looks at the effects of distal ulnectomy, removal of the distal ulnar metaphysis, physis, and epiphysis, on the normal growing thirteen week old foxhound to determine if: 1) carpal instability, 2) abnormal growth of the remaining radius, 3) instability of the interosseous ligament, or 4) other injuries resulting in restricted function of the effected limb occur secondary to the procedure. The second study involves producing distal ulnar epiphysiodesis, bilaterally, in fourteen week old afghan-shepherd mix dogs, allowing them to progress until both clinical and radiographic evidence of growth abnormalities occur, and then performing distal ulnectomy on one leg while allowing the opposite leg to progress serving as a control for comparison to the ulnectomied limb.

Literature Review

Longitudinal growth of long bones is accomplished by the process of enchondral conversion of cartilage to bone. The main parts of the growing bone consist of the epiphysis, physis (growth plate), metaphysis and diaphysis (Fig. 1). In the process of enchondral ossification, germinal cartilage cells, which are closely attached to the epiphysis, proliferate, line up in columns, mature, hypertrophy, calcify, and disintegrate, leaving a straight strip or core of non-cellular calcified cartilage matrix on which new bone is deposited by the osteoblasts. These newly formed cores of bone are termed primary trabeculae and compose the metaphyseal region of bone. The metaphysis is grossly and radiographically flared or increased in diameter. These metaphyseal enlargements are normal for the young growing dog and are most obvious in the distal radius and ulna where growth is most rapid. Above the metaphysis, the diameter of the bone decreases at the remodeling zone where resorption of primary trabeculae is replaced by secondary, then tertiary trabeculae, and finally at the diaphysis is replaced by typical medullary and compact cortical bone.[30,36,37]

As the animal matures and bone growth slows, the bulging of the bone at the growth plate and metaphysis become less apparent and is not identifiable either radiographically or by palpation in the adult dog. In the growing dog this increased metaphyseal width is necessary to provide enough tissue to support the weight of the dog without injuring the newly formed soft bone.[36]

The most important factors regulating normal enchondral bone growth are the integrity of the vascular supplies and the transmission of stresses and strains through the physis. The vacular supply to a major physis of a long bone is comprised of the proximal and distal branches of the nutrient vessels, the metaphyseal vessels, and the epiphyseal vessels. The epiphyseal vessels provide an extensive vascular network that provides a high concentration of nutrients for the germinal cells of the physis.[30,31]

The physis is the weak link in the chain of bones and ligaments that comprise the limb. It is through the zone of hypertrophied cartilage of the physis that fractures occur due to trauma, excessive strains or other forces.[30] In the zone of growth or proliferation of the physis, a collagenous matrix between the chondrocytes provides strength. In the zone of cartilage transformation, calcification provides strength, but the area of chondrocyte hypertrophy has no structural support and thus provides a natural cleavage line.[23] As in children, the strength of the fibrous joint capsule and ligaments is stronger than the metaphyseal-epiphyseal junction, and thus dislocations and sprains are unlikely in the young growing dog.[23,30]

A system of classifying physeal fractures as well as providing prognostic information was developed by Salter and Harris.[39] O'Brien modified Salter's classification to veterinary orthopedics,[30] and Llewellyn further expounded upon it.[23]

This classification is based on detailed radiographic evaluation of the degree and extent of physeal damage. The radiographic findings are an indirect assessment of the integrity of the germinal cells and extent of disruption of the blood supply to these cells. The classification is basically divided into five types with the first type being the least traumatic and having the best prognosis. In this type, the fracture extends through the zone of hypertrophied cartilage cells and damage to the germinal cells and their blood supply is minimal. Type II is basically the same except the fracture line also passes into the metaphysis resulting in a triangular shaped fragment attached to the physis. This is a very common type of physeal fracture seen in veterinary medicine. Types III and IV involve the fracture crossing the physis and through the epiphysis (Type III) or across the physis and through both the metaphysis and epiphysis (Type IV). These physeal fractures are associated with a guarded prognosis because not only are the germinal cells involved, but also their blood supply may be damaged significantly. An additional factor in these two types is that articular surfaces are involved and strict anatomical reduction is a must to prevent secondary osteoarthrosis due to joint incongruity. Type V physeal fractures are not actually associated with displacement but rather compression of the physis, thereby crushing the germinal cells and disrupting continued growth. The prognosis is very poor for continued normal growth with this type of injury to the physis. Type V physeal injury occurs with a rather high frequency in the distal ulna of the young dog having sustained a fracture to the distal radius and/or ulna.

Limb deformities due to growth abnormalities are not an uncommon occurrance in young growing dogs. Growth deformities due to physeal damage can manifest as reduced longitudinal bone growth only or in combination with angulation of the extremity distal to the affected physis,[30] with or without torsional aberrations. Reduction in longitudinal growth can occur due to a slowing of enchondral bone formation in a physis or complete premature closure. Temporary delay within the physis is usually of no clinical significance, whereas complete closure can be of marked clinical significance depending upon the growth potential remaining in the physis at time of injury. Angulation as a result of physeal damage can result from partial closure of a single physis where a significant portion of the growth plate fuses and the uninjured portion continues in growth, or it can result from complete closure of one of two physes at the end of closely aligned long bones, such as the radius and ulna (Fig 2).[30] Other less frequently observed phenomena producing growth alterations result from accelerated rate of growth in one physis of a pair,[13,30,33,37] hypertrophic osteodystrophy, nutritional secondary hyperparathyroidism, retained endochondral cartilage cores, and more recently premature closure of the distal ulnar physis has been shown to be a recessive inherited genetic trait in Skye Terriers.[20,27,37,42]

The canine radius and ulna differ anatomically and their growth plates grow at different rates.[37,40] The radius and ulna each have two physes. The radial proximal growth plate contributes approximately 40% to longitudinal growth, while the remaining 60% occurs from the distal growth plate.[29] The ulnar proximal physis only contributes growth to the proximal ulna, that is to the olecranon, and does not contribute to longitudinal growth of the ulna below the elbow joint. The proximal ulnar physis therefore contributes only 15% to the total longitudinal growth of the ulna. The distal ulnar physis on the other hand is considered to contribute 85% of the total length of the ulna, thus providing all the length distal to the humeroradial joint.[5,37,40] For normal growth, the distal ulnar physis must, therefore, grow at a rate equal to the proximal and distal radial physes combined. An alteration in the relationship of the radius and ulna must occur to provide constant congruity between the proximal articular surface of the radius and the adjacent articular surface of the coronoid process. This mandatory synchronous alteration in relationship of the radius and ulna during growth is best exemplified by the work of Noser, et al., and clinically by Alexander et al.[1,29]

The distal ulnar physis of the dog is conical in shape which seems to be unique to the dog.[5,10,23,40] The conical shape has both beneficial and detrimental effects. The conical configuration allows accelerated growth to occur at this physis. Mathematically, the area of a cone increases the growth surface by 1.5 times over a flat area of the same diameter.[33,37] In other animals and man, the radial and ulnar physes are flat and have the ability to shear when forces are applied producing a Type I physeal fracture. The germinal cells remain attached to the epiphysis and prognosis for uninterrupted growth is good. Due to its conical shape the canine distal ulnar physis is not able to shear regardless of the shearing, axial or lateral forces placed on the forelimb. Instead the apex of the ulnar metaphysis is driven into the distal epiphysis thereby producing a crushing injury to the germinal cell layer predisposing to partial or complete premature cessation of growth.[5,10,40]

Forelimb deformities resulting from premature closure of the distal ulnar physis is the most common complication of physeal injury in the dog.[1,4-7,10,17,27,30,31,34,35,40] The syndrome associated with premature retardation or cessation of the distal ulnar physis is commonly termed "radius curvus". This term is descriptive in nature and attempts to characterize the deformity occurring secondary to premature closure of the distal ulna.

The anatomy of the forelimb must be considered to understand the specific deformities that occur. The ulna extends from a medial position at the elbow obliquely across the long axis of the posterior radius to a lateral position at the carpus slightly caudal to the radius. Proximally the ulna articulates with the humeral trochlea via the trochlear notch and anconeal process, with the medial humeral condyle via the prominent medial projection of the coronoid process, and with the articular circumference of the radius by the radial notch and lateral projection of the coronoid process. Distally the ulna articulates with the ulnar notch of the radius, and with the ulnar carpal and accessory carpal bones by means of the styloid process.[26] When the physis fuses, longitudinal ulnar growth ceases, and the ulna acts like a retarding strap wrapped around the radius. As the radius continues to grow three deformities occur: anterior curvature of the distal radius; distal lateral deviation producing a valgus deformity of the carpo-metacarpus; and external rotation or supination of the distal extremity. As these deformities progress, posterolateral subluxation of the carpal joint occurs causing stretching of the medial and palmar supporting structures. Distal subluxation of the proximal ulna develops as the radial head pushes the humeral condyles out of the trocheal notch. Lateral deviation of the elbow joint results from proximolateral displacement of the radial head, as well as the distal ulnar subluxation (Fig. 2). A progressive osteoarthrosis ensues secondary to abnormal articulation in the elbow and/or carpus. The clinically occuring syndrome has been reported[7,25,27,30,31,35,40] and has been experimentally reproduced by surgically stapling[10,16,17] and by x-irradiation[4,5,6] of the distal ulnar physis.

Diagnosis of distal ulnar physeal closure is based on signalment, a complete history, physical examination and radiography. The signalment and history are important factors early in the syndrome prior to overt deformities of the forelimb. The typical animal presented will be a medium to giant breed dog between four and six months of age with a history of trauma to the forelimb several weeks earlier. At presentation the dog may be favoring the affected leg, and varying degrees of lateral deviation of the distal extremity will be present. On physical examination, minimal to no pain will be elicited on palpation of the affected limb. If pain is elicited, it will be associated with full extension of the elbow. Trauma is not always a concomittant historical finding, and when it is, it may be associated with a previous fracture. In one report of 58 dogs with early closure of the distal ulnar physis, 34 dogs had no history of previous trauma.[35]

Radiography is required for definitive diagnosis. With any growth deformity either suspected or present, radiographs which include the elbow and metacarpus should be taken of both forelimbs for comparison of the physes and assessment of the degree of deformity and joint changes.[7,31,47] The radiographic changes associated with both clinical and experimental premature closure of the distal ulnar physis are described by numerous authors in the literature.[4,5,6,7,17,31,35,40,47] The more salient radiographic findings associated with this syndrome are: 1) closure of the distal ulnar physis as evidenced by narrowing at the apex of the conical physis; 2) bowing of the distal 1/3 of the radius in an anterior and medial-lateral direction; 3) separation of the radial and ulnar diaphyses; 4) angulation of the distal radial epiphysis producing a lateral deviation of the carpo-metacarpus (valgus); 5) increased diameter of the distal ulnar diaphysis with ulnar shortening; 6) posterior subluxation of antebrachiocarpal joint; and 7) subluxation of the elbow with distal displacement of the proximal ulna and anterolateral displacement of the radial head resulting in lateral deviation of the elbow and secondary arthrosis (Fig 2). The severity of radiographic and clinical findings will vary markedly and is dependent upon the age of the dog at physeal closure, the degree of physeal closure and the duration of physeal closure.

Growth deformities, especially involving the radius and ulna, are complicated problems requiring early and precise diagnosis and surgical management. Splints and casts are seldom effective in treating carpal angulation due to premature physeal closure. External support can not prevent the disproportionate bone growth which distorts the limb and multiple pressure sores result.[47] Surgical management of growth deformities resulting from premature physeal closure is covered extensively in the literature.[3,7,8,10,13,19,21,25,27,28,34,35,38,45-47]

Treatment will vary depending upon a number of factors. Factors that should be considered are: 1) age of the animal dictating the residual growth potential, 2) physis involved, 3) degree of deformity present, and 4) difficulty of the surgical procedure. Surgical treatment of distal ulnar physeal closure has basically taken one of two approaches. If growth is complete or near term, 7-9 months, an osteotomy of the radius and ulna is performed at the point of greatest angulation, and the limb straightened. Stabilization of this osteotomy is critical and requires rigid fixation with either compression bone plating or full Kirschner-Ehmer apparatus. If elbow subluxation is present, a second procedure is required to either lengthen the ulna or shorten the radius.

If a significant amount of radial growth potential still exists some surgeons have advocated stapling the distal radial physis to correct the angular deformity.[3,7,8,9,35,47] Others have attempted to release the retarding effect of the ulna thus preventing further progression of deformities and maintaining longitudinal growth. Segmental osteotomy alone or in conjunction with a Stader-Charnley spreading apparatus has been used to delay regrowth of the ulna. If the angular deformity of the radius was severe, radial osteotomy was performed at the same time.

In the past four years, alternate approaches to the problem of early closure of the distal ulnar physis with significant growth potential remaining have been advocated. A common goal of these approaches has been complete removal of the distal ulnar metaphysis, physis and proximal aspect of the distal epiphysis leaving the styloid process. Egger and Stoll stressed the importance of the ligamentous attachments of the styloid process to lateral and palmar carpal stability.[10] They recommend uniting the styloid process to the distal radial epiphysis with either multiple K-wires or lag screw fixation. Mason and Baker[25] and Griffiths,[12] on the other hand, left the styloid process intact with only its ligamentous attachments to the distal radius without untoward carpal effects. Distal ulnectomy performed early in the syndrome before major deformities develop has been shown to correct existing elbow and angular deformities by release of the radius with increased growth rate from the radial physis of the shortened side.[12,15] Release also results in re-establishment of the normal alteration in relationship that must occur with longitudinal growth of the radius and ulna.

Materials and Methods

Group I

Eight thirteen week old foxhound puppies, six female and two male, were obtained. These puppies were healthy, vaccinated dewormed littermates. All puppies were kept in 3'x6' kennels and fed a commercial puppy chow with no additives throughout the study.

Preoperative radiographs were taken of the antebrachium including the elbow and carpus, bilaterally, to determine that no growth or congenital abnormalities existed.

At surgery the left distal ulna was approached and the distal metaphysis, physis and epiphysis removed. A Kirschner wire (K-wire) was placed in the radial diaphysis near mid-shaft and another placed in the distal radial epiphysis. The right distal ulna was also approached, similarly to the left, but was not removed. K-wires were placed as previously described (Fig. 3). Postoperatively metasplints were placed on both forelegs of all puppies for three weeks.

Radiographs were taken immediately postoperatively, at two week intervals until one month postoperatively, and then at monthly intervals until six months post-op which time the study was terminated. Standard anteroposterior (AP) and lateral views were taken to include the elbow and carpus, bilaterally. Periodically, carpal series were included in the radiographic study.

Measurements of radial growth were taken from the mid-point of each K-wire on the AP radiograph. Growth of the control and ulnectomied limbs were graphed (Fig. 4). All dogs were examined three times weekly for development of gait or conformational abnormalities throughout the study by the primary investigator.

At termination of the study, all dogs were euthanized, necropsied, and the forelimbs removed for examination of gross change. The elbow and carpal joints were opened systematically and examined for evidence of articular defects and lack of ligamentous stability. Photographs were taken of the first six forelimbs placed adjacent one another for comparison.

Group II

Four healthy, vaccinated, fourteen week old sibling afghan-shepherd cross puppies were subjected to distal ulnar epiphysiodesis, bilaterally, by placing 4.0mm cancellous bone screws in lag fashion across the distal ulnar physis. These puppies were housed under similar conditions as the foxhounds in Group I and were observed three times weekly for development of gait and/or conformational abnormalities.

Four and one half weeks post-epiphysiodesis, clinical and radiographic evidence of growth deformities of the elbow and distal forelimb was noted (Fig. 5). At that time, the right distal ulna selected at random, was removed surgically as previously described in Group I. The left leg was allowed to progress without surgery for comparison with the ulnectomied leg. The right foreleg was placed in a metasplint or Robert Jones bandage (dog 4) for two weeks postoperatively.

Radiographs were taken of both antebrachii including the elbow and carpus on all puppies pre-epiphysiodesis and immediately postoperatively. Radiographs were also taken pre-ulnectomy and post-ulnectomy, at two week intervals post-ulnectomy until one month postoperatively, and then at monthly intervals until final radiographs were taken six months postoperatively.

At termination of the study, all dogs were euthanized, necropsied, and the forelimbs removed for examination of gross change. All brachial musculature was removed leaving the antebrachial and more distal muscles intact for photographs of the limbs adjacent one another. After photographs, the elbow and carpal joints were opened and examined for evidence of arthrosis secondary to improper growth or articulation. Photographs were taken of each elbow joint and selected carpii. Histopathological sections were taken from the elbow joints of dogs 1-3. Representative samples from each elbow joint were taken from the erosive areas and normal areas of the humeral head, trochlear notch of the ulna and radial head. These joint samples with underlying subchondral bone were placed in 10% buffered neutral formalin for one week and then decalcified in 20% formic acid. The samples were embedded in paraffin, sliced on a microtome at eight microns and routinely stained with hemotoxylin and eosin. The forelegs of dog 4 were deboned and prepared for a prosection specimen.

Surgical Procedure

Group I

Distal Ulnectomy

All dogs were atropinized at a rate of .04 mg/pound body weight and then induced with thiamylal sodium (8 mg/# BW). Endotrachael tubes were passed and the dogs were maintained on halothane/oxygen combination.

Both forelegs were clipped from the metacarpo-phalangeal joints to the proximal humerus and the unclipped distal foot wrapped. The dogs were positioned in dorsal recumbency with both forelimbs suspended and then prepared for aseptic surgery in a "hanging-leg" fashion. Both forelimbs were quarter draped and the distal foot wrapped in sterile linen after being cut down. Both forelimbs were passed through the same fenestrated drape and one limb operated on at a time.

The left distal ulna was approached through an 8-10 cm lateral skin incision beginning approximately midshaft and ending over the ulnar carpal bone. The subcutaneous tissues and superficial fascia were incised similarly. The incision was deepened between the tendons of the ulnaris lateralis and the lateral digital extensor muscles. The heavy fascial attachments over the distal ulna were freed with a periosteal elevator and osteotomy performed with an osteotome approximately 1.5 cm proximal to the physis so the entire metaphysis was included. The periosteum was removed with the distal ulna using both blunt and sharp dissection. Ligamentous attachments between the distal ulnar and radial epiphyses were severed and the joint capsule opened to expose the lateral styloid process. The lateral collateral and palmar ulnocarpal ligaments were severed as close to the styloid process as possible and the distal ulna removed. The joint capsule was closed with #3-0 dexon in cruciate mattress sutures.

Two Kirschner wires were placed, one in the radial diaphysis near midshaft and one in the distal radial epiphysis. Both were placed in a lateral to medial fashion until they were felt to penetrate the medial cortex at which point the pins were cut as close to the bone as possible. The superficial and deep fascial layers were closed with #3-0 dexon in continuous fashion and the skin was reapposed with a continuous subdermal suture pattern.

The right distal ulna was approached similar to the left ulna with the deep fascial layers freed from it similar to the left, but without an osteotomy and ulnectomy performed. Two Kirshner wires were placed as previously described, as was closure.

Both forelimbs were padded and placed in metal metasplints up to the olecranon post-operatively.

Group II

Distal Ulnar Epiphysiodesis

A 2-3 cm skin incision was made directly over the lateral styloid process to end midcarpus. The subcutaneous tissues and superficial fascia were incised similarly. The tip of the styloid process was identified and a 3 mm incision made over the tip. A 2.0 mm drill bit was used to drill a hole from the tip of the styloid process across the physis into the metaphysis. A 50 mm, 4.0 mm cancellous bone screw was placed and tightened so that it was well seated in the distal metaphysis and compressed the distal ulnar physis. The subcutaneous tissues were closed with #3-0 dexon in continuous pattern and skin closed with #4-0 stainless steel interrupted sutures. This procedure was performed on all dogs, bilaterally, in Group II. Both legs were placed in light support wraps postoperatively.

Distal Ulnectomy

Distal ulnectomy was performed on the right leg four and one half weeks after distal ulnar epiphysiodesis. The procedure was performed as described previously for Group I without the placement of Kirschner wires.

Results

Group I

A. Clinical Effects

All dogs placed weight equally on forelegs when taken out of splints 3 weeks post-ulnectomy. Gaits were somewhat stiff initially but within five days all dogs were walking and running without signs of lameness. The first sign of forelimb deviation was noted in one dog six days after removing splints. A slight lateral deviation (valgus) of the carpometacarpus was noted in the left forelimb. By the end of another ten days four of the eight dogs were exhibiting a slight valgus deformity of the left carpometacarpus. The degree of valgus deformity in dogs became more pronounced in subsequent weeks until a marked lateral deviation and posterior subluxation of the antebrachiocarpal joint resulted, producing a mild lameness secondary to dropping of the distal extremity. The lameness was more noticeable earlier in the progression of the valgus deformity than in the later stages. Weight was borne on the medial aspect of metacarpophalangeal region with no pain on palpation (Fig. 7). Slight muscle atrophy was noted in the distal antebrachium of the four dogs with valgus deformity during the final weeks of the study. The remaining four dogs in Group I progressed without lameness or forelimb deformities throughout the 6 month study

(Fig. 8). On close inspection of the two forelegs held in extension adjacent one another, slight shortening of the left limb as compared to the right was noted.

B. Growth of left and right radius

The left radius was shorter than the right radius in all dogs. The eight dogs basically fell into two groups of radial growth. Four dogs (1, 4, 7, 8) demonstrated a minor reduction in growth - varying from 5.5 mm to 8.5 mm. The remaining four dogs, ones with angular deformity, (2, 3, 5, 6) demonstrated a more severe reduction in left radial growth varying from 17 mm to 22.5 mm. This has been represented graphically (Fig. 4).

C. Physeal closure summary

Disruption of the distal radial physis occurred prematurely in the ulnectomied limb of four dogs (2, 3, 5, 6). Physeal closure times, otherwise, were within normal time intervals.

D. Lengthening of the ulna post-ulnectomy

Lengthening of the left ulna post-ulnectomy occurred in all dogs with the length varying from 10 millimeters to 40 millimeters. The medullary canal appeared radiographically to continue distally with lengthening.

E. Radiography

The right control limbs appeared radiographically normal at all stages of the experiment, as did the bones of the treated limb which were not directly involved in the abnormal growth pattern.

No congenital, metabolic or other abnormalities were found on the pre-ulnectomy radiographs. On evaluation of the post-ulnectomy radiographs, placement of Kirschner wires (K-wires) and ulnectomy were deemed satisfactory.

At two weeks post-ulnectomy a mild periosteal and endosteal reaction was generally noted to the radial diaphyseal K-wires with no reaction to the epiphyseal K-wires. Sclerosis was also noted around the left radial nutrient artery in six of the eight dogs.

At four weeks post-ulnectomy an increased density of the left radial cortices, primarily involving the anterior cortex with narrowing of the medullary canal, was noted in all dogs. Minimal periosteal reaction of the posterior right distal ulnar metaphysis was noted in two dogs. A mild periosteal bone production was also seen associated with the left posterior radial diaphysis near the diaphyseal K-wire in three dogs.

At eight weeks post-ulnectomy the left radial cortices continued to be thickened in all dogs. An anterior bowing of the distal radius was first noticed in four of the eight dogs (dogs 2, 3, 5, 6). These dogs also exhibited premature closure of the lateral aspect of the distal radial physis, producing a mild to moderate lateral deviation of the carpus and foot. Premature closure was evidenced by increased density at the affected site with bridging across the collapsing physis.

Eleven weeks post-ulnectomy left carpal films were taken of two dogs (dogs 5, 6). A type I physeal fracture of the distal radius was noted to be producing moderate to severe lateral deviation distal to the radial physis (Fig. 9).

At twelve weeks post-ulnectomy there was persistent thickening of the radial cortices in all dogs, being more predominate in the posterior distal one half of the four dogs with angular deformities. Five of the eight dogs were demonstrating anterior curvature of the distal radius and four of the dogs a medial to lateral deviation of the distal radius producing a proximolateral to distomedial angular deformity with the carpus and foot. The degree of angulation varied from mild in one dog to marked in the other three dogs producing posterior subluxation of the radiocarpal joint and overriding of the anteromedial radial epiphysis. The intercarpal and carpometacarpal joints appeared normal. In one dog (dog 2) a marked lysis and sclerosis of the distal radial metaphyseal-physeal junction was noted.

At seventeen weeks post-ulnectomy all dogs demonstrated increased left radial cortical thickness, being more pronounced in the posterior distal cortex of four dogs. The left distal ulna in two dogs was noted to be nearing fusion with the posterior radial osteophytes previously noted on four week radiographs. Four dogs demonstrated anterior curvature of distal radius varying from moderate to marked, medial to lateral deviation of the distal radial metaphysis producing angular deformity and moderate to severe lateral deviation of carpometacarpus, distal radial metaphyseal-physeal sclerosis and lysis, and posterior subluxation of the radiocarpal joint with the radial epiphysis overriding anteriorly. The intercarpal and carpometacarpal joints were within normal limits.

At twenty weeks post-ulnectomy all dogs exhibited left radial cortical thickening of similar degree to the seventeen week films. Slight anterior bowing of the left radius of one dog without angular deformities was noted, as was a slight lateral deviation of the left carpometacarpus in another dog without distal radial physeal disruption. Fusion of the left distal ulna to a posterior radial osteophyte was noted in one dog; no abnormalities were seen associated with this occurrence. The four dogs with distal radial physeal disruption demonstrated similar lesions as the seventeen week films, except more sclerosis and lysis was associated with the metaphyseal-physeal junction on these films. This appeared to be due to healing of the previous alterations.

At twenty-five weeks post-ulnectomy all dogs demonstrated increased left radial cortical thickness, most marked in the four dogs with severe angular deformities. One dog continued to demonstrate slight lateral deviation of the carpometacarpus without other abnormalities, as does another dog with mild anterior radial bowing. Fusion of the left distal ulna with the posterior distal one half of the radius was noted in two dogs without complications. The four dogs with distal radial physeal disruption showed marked anterior curvature of the distal one half of the radius, marked medial to lateral deviation of the distal metaphysis producing a proximolateral to distomedial angular deformity and lateral deviation of the carpometacarpus, and posterior subluxation of the radiocarpal joint with the radial epiphysis overriding anteromedially. The intercarpal and carpometacarpal joints continued to be within normal radiographic limits (Fig. 10). The distal metaphyseal-physeal junction was noted to be uniform in density and contour as if healing was complete.

F. Gross pathology

Right foreleg - All dogs

The articular cartilage on the distal humerus and proximal radius appeared grossly normal. Superficial erosion of the proximal ulna was noted in seven of the eight dogs as a superficial erosion of the distal lateral one half of the trochlear notch varying in area from .5 X 1 millimeter to 2 X 3 millimeters. No abnormalities were noted on opening the carpii of any of the dogs.

Left foreleg - All dogs

The articular cartilage on the distal humerus and proximal radius appeared grossly normal. Superficial erosion of the distal lateral one half of the trochlear notch was noted in five of the eight dogs with the largest area involved being 3 X 3 X 4 millimeters. Abnormal carpal findings were limited to erosion of the lateral aspect of the ulnar carpal bone in four of the eight dogs, dogs 1, 4, 7, 8. The other four dogs exhibited more severe lesions of the distal radius and carpus. An angular deformity of the distal radius in a proximolateral to distomedial direction producing a lateral deviation of the carpometacarpus was noted. The lateral aspect of the distal radius was shortened with the medial aspect elongated producing lipping of the medial styloid process over the radial carpal bone. Hypertrophy of the ligamentous attachments on the craniomedial and lateral aspects of the radiocarpal joint were noted being most marked in dogs 5 and 6. A minimal amount of brownish discoloration of the synovium was seen around the accessory carpal bone in three of the four dogs.

Erosion of the lateral ulnar carpal bone was also noted in these dogs.

Group II

A. Clinical Effects

Valgus deformity of the carpus producing lateral deviation of the foot was first noted two weeks post-epiphysiodesis in three of the four dogs. By three weeks post-fusion, all dogs were showing minor valgus deformity. Four and one half weeks post-epiphysiodesis all dogs were exhibiting lateral deviation of the foot of varying degrees in both forelegs. One dog (#4) also had marked anterior bowing of the right distal radius and posterior subluxation of the carpus. At this time a right distal ulnectomy was performed on all dogs while the left ulna was left to progress. Two weeks post-ulnectomy splints were removed. All dogs placed weight on the right leg but were moderately lame. All dogs were more dropped (dorsoflexion) in the right carpus than the left, and one dog exhibited marked lateral deviation of left elbow (7 weeks post-epiphysiodesis). As the study progressed all dogs developed marked anterior bowing of the left radius, valgus deformity and posterior subluxation of the carpus, and lateral deviation of the left elbow (Fig. 2). These deformities developed first and were most severe in dogs 1 and 3. As the deformities associated with distal ulnar physeal closure in the left leg progressed, weight bearing and use of the leg diminished. Marked muscle atrophy in the left leg developed as the limb became less functional. By eleven weeks post-ulnectomy (15.5 weeks post-epiphysiodesis) the left foreleg was essentially non-weight bearing in dogs 1 & 3, used only minimally by dog 2, and used moderately by dog 4. As use of the left foreleg diminished, the ulnectomied right leg assumed weight bearing. The right leg became the dominant weight bearer in dogs 1 & 3 by four weeks post-ulnectomy (8.5 weeks post-epiphysiodesis), by six weeks post-ulnectomy in dog 2, and by nine weeks post-ulnectomy in dog 4. Throughout the post-ulnectomy period, dogs 1, 2 & 3 remained markedly dropped in the right carpus even though they were full weight bearing and without pain on manipulation of the carpus (Fig. 11). Palpation and manipulation of the right carpus in all dogs at 18 weeks post-ulnectomy (22.5 weeks post-epiphysiodesis) demonstrated no pain with moderate joint laxity in all dogs and crepitace in three dogs. Dog 4 progressed somewhat different from the other three dogs of Group II. Deformities developed rapidly in the right foreleg post-epiphysiodesis so that by the 4.5 week post-operative period marked anterior curvature of the distal radius, valgus deformity and posterior carpal subluxation had occurred (Fig. 12). The left forelimb was only minimally affected at the same time. In the post-ulnectomy period, the right forelimb straightened markedly, both in the anterior-posterior and medial-lateral plane. The amount of palmar dropping also improved so that minor anterior bowing, valgus deviation and dropping in the carpus resulted. The left distal epiphysiodesis progressed much slower in dog 4 so that it remained a functional limb until 15-16 weeks post-ulnectomy.

B. Physeal closure summary

Physes of the left radius as a general rule closed before physes of the right radius, with all left proximal radial physes closing prior to the right. In two dogs, the left proximal radial physis closed 11 and 12 weeks earlier than the corresponding right physis.

C. Lengthening of the ulna post-ulnectomy

Lengthening of the right ulna post-ulnectomy occurred in all dogs with the length varying from 18 millimeters to 29 millimeters. The medullary canals appeared radiographically to continue distally with lengthening.

D. Radiography

Pre-epiphysiodesis radiographs revealed both forelimbs of all dogs to be radiographically normal. Post-epiphysiodesis, screw placement and compression across the distal ulnar physis was judged to be satisfactory in all dogs.

At four and one half weeks post-epiphysiodesis, prior to ulnectomy, complete closure of the distal ulnar physis was noted in all but one leg (dog 4 left leg). The salient radiographic features were 1) shortening of the ulna, 2) subluxation of humeroulnar joint with increased joint space, 3) anterior curvature of distal radius, 4) posterior subluxation of the radiocarpal joint, 5) thickening of the posterior radial cortex, and 7) narrowing of the proximal radial physis (Fig. 5 and 12). Moderate lateral deviation of the right foot with an increased width of the medial distal radial physis was noted in dog 4 which was not an outstanding feature of the other dogs. Comparison of dog 4 with the other dogs revealed certain features to be less pronounced and other features to be more pronounced. The anterior radial curvature was much more pronounced while only slight elbow subluxation was noted as compared to the other dogs (Fig. 5 and 12). The left foreleg of dog 4 was essentially normal as only partial closure of the distal ulnar physis had occurred at the apex producing slight shortening of the ulna.

Evaluation of the post-ulnectomy films - right leg only - revealed the osteotomy to be satisfactory. Elbow subluxation in dog 4 appeared to be corrected and decreased in dog 1.

At two weeks post-ulnectomy elbow subluxation was no longer present in any of the right ulnectomied limbs, whereas the subluxation had become more pronounced in the unoperated limbs. The amount of anterior radial curvature and posterior subluxation of the radiocarpal joint had decreased in the ulnectomied limb and increased in the opposite limb. The posterior distal radial cortex was increased in thickness in all limbs, and anterior ulnar cortical thickening was noted in all intact ulnas. Osteoporosis was seen in two dogs associated with the right limbs only, and narrowing of the proximal radial physis was noted in three dogs, the left limb only. Lateral deviation of the foot had become mild in the unoperated left leg of all dogs, while the moderate lateral deviation of the right foot of dog 4 had become only a slight deviation.

At four weeks post-ulnectomy mild anterior distal radial curvature and slight posterior subluxation of the radiocarpal joint was noted to be still present in the ulnectomied right limbs but less than two weeks previously. Lateral deviation of right foot in dog 4 was no longer evident. An increased density of the posterior radial cortex was noted in all limbs with an increased density of the anterior ulnar cortex noted in all left limbs. The unoperated left limbs demonstrated lack of ulnar growth with continued radial growth resulting in increased subluxation of the humeroulnar joint, anterior curvature of the distal radius, posterior subluxation of the radiocarpal joint and lateral deviation of the foot. These findings were milder in two dogs (dogs 2, 4) and more severe in the other dogs. The elbow subluxation in dogs 1 and 3 has produced deformity of the anconeal process and lateral deviation of the elbow joint with medial angulation of the olecranon. Dog 1 also showed trochlear notch deformity, soft tissue swelling along the medial aspect of the elbow joint, and a lytic area at the medial humeral epicondyle. Both dogs exhibited marked muscle atrophy in the left antebrachii as well as generalized osteoporosis.

At eight weeks post-ulnectomy all ulnectomied right limbs were noted to retain deformities noted four weeks previously, that is, mild anterior curvature of distal radius, slight posterior subluxation of radiocarpal joint, and increased density of posterior radial cortices. Lack of ulnar growth in the left limbs had continued with increased severity of elbow subluxation and resultant deformities of the anconeal process and trochlear notch in three dogs. No gross deformities of the proximal ulna and distal humerus were noted in dog 4. Two dogs showed worsening of lateral elbow deviation and accompanying soft tissue swelling as well as medial deviation of the olecranon and proximal ulna. Anterior curvature of the left distal radius was more pronounced in all dogs as was increased cortical thickening of the posterior radius and anterior ulna. Moderate posterior subluxation of the left radiocarpal joint and moderate lateral deviation of the foot were noted in all dogs. Increased distance between the radius and ulna was noted in one dog as well as an outward rotation of the distal extremity.

At thirteen weeks post-ulnectomy all ulnectomied right limbs demonstrated similar radiographic signs as the eight week films. Mild anterior radial curvature, slight posterior subluxation of the radiocarpal joint, and increased density of the radial cortices remained. Slight lateral deviation of the carpometacarpus was also noted in one ulnectomied limb, dog 3. The unoperated left limbs continued to deteriorate with marked elbow subluxation resulting in deformities of the anconeal process, trochlear notch and radial head in three dogs. Lateral deviation of the elbow joint with medial deviation of the olecranon was noted to be mild in two dogs and moderate in the other two dogs with marked muscle atrophy of the antebrachium. One dog (dog 1) appeared to have a boney ossicle within the lateral aspect of the elbow joint. Anterior radial curvature was marked in three dogs and all dogs showed thickened posterior radial and anterior ulnar cortices. Moderate posterior radiocarpal subluxation, outward rotation of the distal antebrachium and pes, and lateral deviation of the carpometacarpus were also noted as sequelae to the progressive deformities produced by early distal ulnar physeal closure. Some irregularities of the left distal metaphysis were noted in two dogs.

At sixteen weeks post-ulnectomy all ulnectomied right limbs remain essentially unchanged; mild anterior curvature of the distal radius with slight posterior subluxation of the radiocarpal joints. Outward rotation of the right distal antebrachium was also noted in one dog, dog 4. Lesions associated with the left forelimbs - elbow deformities, angular deformities, rotational deformities, and radiocarpal deformities - were noted to be progressing in severity but at a slower rate than previously noted.

At twenty and twenty-five weeks post-ulnectomy the changes noted were similar. There was mild anterior curvature of the distal radius with slight posterior subluxation of the radiocarpal joint noted in the right ulnectomied limbs. A slight lateral deviation of the foot was noted in one right limb. In the left unoperated limbs, generalized osteoporosis, muscle atrophy and degenerative joint disease were noted to be associated with the marked deformities of the proximal radius, ulna, and distal humerus. A marked degree of anterior radial curvature, separation of the radius and ulna, subluxation of the radiocarpal joint, lateral deviation of the foot, and outward rotation of the distal antebrachium and pes were the prominent radiographic features noted (Fig. 2).

E. Gross pathology

Right foreleg - All dogs

The articular cartilage on the distal humerus and proximal radius appeared normal grossly, as did the synovium and synovial fluids. Mild to moderate erosion of the articular cartilage of the distal lateral one half of the trochlear notch was noted. Abnormalities of the carpus of 3 dogs were limited to erosion of the articular cartilage of the lateral aspect of ulnar carpal bone. In one dog (dog 4) cartilage erosion was also seen on the lateral aspect of the radius, 2 X 3.5 millimeters, and fibrin spots were noted diffuse over the anterior-dorsal one half of the radial carpal bone with superficial erosion.

Left foreleg - All dogs

Gross lesions associated with the elbow joint were similar in all dogs but of a more advanced state in dogs 1 and 3. On opening the thickened joint capsule an increased amount of brownish discolored synovial fluid of decreased viscosity was noted. The interior of the joint capsule had brownish discolored, mottled areas. There was gross deformity of the proximal ulna, humeral condyles and radial head with degenerative lesions involving 50-90% of the articular surfaces. Periarticular osteophytes were noted in dogs 1 and 3. The radial head was displaced upward, lateral, and rotated outward so that the medial surface was directed anteriorly. The medial humeral epicondyle was displaced anterior and lateral in dogs 1 and 3. The trochlear notch was malformed with marked degenerative changes and erosion of articular cartilage and subchondral bone. The anconeal process was badly deformed and flattened in dogs 1 and 3. A boney ossicle was noted attached to the lateral joint capsule of dog 3 (Fig. 13). The olecranon and anconeal process were rotated and shifted in a medial position relative to the radius and distal humerus.

Gross lesions of the carpal joints were again more advanced in dogs 1 and 3. Mild erosion of the articular cartilage of the dorsal ulnar carpal bone was noted in 3 dogs. Dog 4 also had mild articular cartilage erosion along the anterior aspect of the radial carpal bone and a 1 millimeter punctate erosion of the articular surface of the accessory carpal bone facing the ulnar carpal bone. All carpii demonstrated posterior subluxation and lateral angulation with respect to the distal radius and ulna. The lateral collateral ligament appeared to be intact.

F. Histopathology

All sections from the left elbow, unoperated forelimb, demonstrated a non-inflammatory degenerative joint disease of advanced nature. Sections from the right elbow were normal in all dogs with the exception of sections taken from the eroded surfaces of the distal lateral aspect of the trochlear notch of the ulna. These sections demonstrated mild to advanced cartilage erosion with replacement by fibrous tissue.

Discussion

Group I

The effects of complete distal ulnectomy, removal of the distal metaphysis, physis and epiphysis, have not been researched. As a result, there has been reluctance to use this procedure as a means of surgical management of premature closure of the distal ulnar physis. It was theorized by Egger et al.[10] that removal of the styloid process would result in carpal instability. He and others have advocated removal of the distal ulna without removal of the styloid process.[12,25]

In Group I dogs, lack of carpal stability secondary to removal of the styloid process was not a clinical finding, but abnormalities did develop. The first sign of forelimb deformity occurred in one dog six days after removal of the metasplints. By the end of another ten days three additional dogs were showing slight lateral deviation of the foot. Over the remainder of the study four dogs progressed without forelimb deformities while the other four developed angular deformity of the ulnectomied limb. These deformities progressed to a marked lateral deviation of the carpometacarpus and posterior subluxation of the radiocarpal joint (Fig 7).

Angular deformities of the forelimb are of two basic types, those caused by distal ulnar physeal closure and those caused by partial closure of the distal radial physis of which the lateral aspect of the physis tends to be most common.[28] Since the former was an impossibility, the angular deformity was determined to be caused by lateral radial physeal closure. This was felt to be caused by stress protection of the distal radius while in the splints resulting in trauma to the lateral aspect of the radial physis by the active young dogs when taken out of the splints.

Radiographs taken four weeks post-ulnectomy did not reveal radiographic abnormalities associated with the distal radial physes. The left radial cortices were beginning to increase in density as a result of increased stress placed on the radius. It was not until the eight week post-ulnectomy radiographs that disto-lateral ulnar physeal closure was diagnosed. This was evidenced by increased density at the effected site with bridging across the collapsing physis. Two of the four dogs developed marked lateral deviation of the foot more rapidly than the others. A carpal series at eleven weeks post-ulnectomy of these two dogs revealed both to have sustained a type I physeal fracture (Fig. 9). No attempt was made to correct the fracture, so as not to alter the study.

At no time in the progression of the dogs with disruption of the distal radial physis did elbow abnormalities develop. Humero-radial, as well as humero-ulnar subluxation occurs secondary to distal radial physeal closure in the usual case due to continued growth of the ulna.[28,32,34] In these dogs a complete ulna was not present to produce the expected effects. The elbow joints throughout the study remained radiographically normal in all dogs (Fig. 10). It was interesting to note how much angular deformity resulted even though the elbow was not affected. In all dogs with distal radial disruption, marked to severe deformities of the distal radius resulted. Curvature of the distal radius occurred in both an anteroposterior and medial to lateral plane producing severe lateral deviation of the carpometacarpus and posterior subluxation of the radiocarpal joint with overriding of the exaggerated medial radial epiphysis.

Changes of stress patterns on bone will result in remodeling of the bone according to Wolff's Law, so that the areas under most stress are reinforced. This principle was well demonstrated in the radius of the ulnectomied limb. At two weeks post-ulnectomy sclerosis was noted around the left radial nutrient artery in six of the eight dogs. At four weeks post-ulnectomy an increased density of the left radial cortices was noted in all dogs. As the radius had to assume increased stresses and strains imposed upon it by removal of the distal ulna, its cortices adjusted by increasing in density and structure. The increased osteogenesis required more blood supply as evidenced by the sclerosis associated with the nutrient arteries.

Lack of normal longitudinal growth of the left radius was noted in all dogs of the study. This varied from minor overall shortening in four dogs to a more marked overall shortening in the other four dogs (Fig. 4). Some reduced growth of the ulnectomied limb would not be an unexpected finding. Without support from the ulna, the radius would have to assume added stresses and strains. This would in turn be transmitted to the growth plates as added forces or pressures applied across the growth plate. Pressures applied across a growth plate by metal pins, screws or wire loops have been shown to lead to a reduction of longitudinal growth.[29,43,46] The greater reduction of radial growth noted in one half of the dogs was a result, not only from reduction of longitudinal growth, but more importantly from disruption of the distal radial physis by either premature closure or physeal separation. Graphs of individual growth curves are located in the appendix.

Physeal closure, with the exception of the four disrupted distal radial physes, was within accepted normal time intervals,[18,41,44] and as a general rule were comparable between similar physes of the left and right limb.

An interesting finding which developed during the study, was lengthening of the ulna post-ulnectomy. This phenomena occurred in all dogs to greater or lesser degree (10-40 millimeters). The medullary cavity appeared radiographically to continue distal with lengthening. Growth from the proximal radial physis could not produce lengthening distal to the coronoid process of the ulna without causing disruption of the elbow joint. Lengthening, therefore, had to occur from the osteotomy site. The lengthening of greatest magnitude, in two dogs, was associated with joining of the osteotomy site with osseous tissue distal to it. The origin of the osseous tissue was felt to be from remnants of periosteum left during the ulnectomy which reacted in response to injury. Joining of the osteotomy site with osseous tissue, however, was not true in all instances. In one dog, osseous tissue was noted eleven millimeters distal to osteotomy site and extended four millimeters distally. The total ulnar lengthening in this dog was only ten millimeters and never joined with the osseous tissue which became less prominent with time. In the past, regrowth of ulnar osteotomies was associated with a combined effort of growth from both distal and proximal bone fragments as would be expected with normal bone healing. Lengthening of the ulna post-ulnectomy could be associated with a similar stimulus.

Gross changes of the elbow in this group of dogs were confined to the distal half of the lateral trochlear notch where superficial erosion of the articular cartilage occurred. The extent of erosion varied somewhat among dogs and was considered mild in all cases, with the largest area observed being 3 X 3 X 4 milimeters in one dog. Interestingly, seven of the dogs had lesions in the control limb whereas only five of the eight had lesions in the ulnectomied limb. Similar lesions have been reported in dogs with reduction of longitudinal ulnar growth from distal ulnar physeal retardation,[4,6] and also in dogs where asynchronous growth of the radius and ulna occurred secondary to cross pinning the radius to the ulna.[29] Lesions in these instances were attributed to distal ulnar subluxation resulting in loss of articular contact with the distal humerus. It has been shown that loss of proper articular contact and movement, results in inadequate diffusion of nutrients to the cartilage and its degeneration.[6,11,14,22,24] In one study, similar lesions were also found in the unpinned control limbs where asynchronous growth did not occur. It was stated that these changes were more obvious in the limbs where extensive change was present in the opposite cross-pinned limb. The dogs in this study would not be expected to have asynchronous growth of the radius and ulna. If it occurred, it was of very minor degree so that no clinical or radiographic evidence was seen. I would be in agreement with Carrig, et al. "that even lack of articular contact of minor proportions can result in degenerative changes in cartilage."[4] These lesions could occur in normal joints secondary to added stresses and be of questionable significance. As the degree of subluxation increases, the depth of erosion increases concurrently so that erosion to subchondral bone is not uncommon with prolonged subluxation of moderate to marked degree.[29]

Abnormal carpal lesions were confined to the ulnectomied limbs. In four dogs, superficial erosions of the lateral aspect of the ulnar carpal bone were found. These lesions were attributed to lack of articular contact with the styloid process. The other four dogs exhibited more severe lesions related to the angular deformities produced by distal radial physeal disruption. With closure of the lateral aspect of the physis and continued growth of the medial side, a proximolateral to distomedial angular deformity resulted. Continued growth of the medial aspect of the radius also produced an elongated medial styloid process which overlapped the radial carpal bone. As angulation and lateral deviation of the foot became more severe, stretching of the medial fascial, ligamentous and tendinous supporting structures occurred resulting in their hypertrophy. Erosion of the ulnar carpal bone was also seen in these dogs resulting from improper articulation with the shortened ulna.

Group II

Fusion of the distal ulnar physis has been experimentally produced by surgically stapling across the physis,[10,16] and by irradiation of the physis.[4,5,6] The use of a lag screw across the physis has not been reported in the literature as a means of producing distal ulnar physeal closure, although, it is common knowledge that any implant across a growing physis has the potential of retarding or closing the physis.[43,46] In this project, lag screws were shown to produce closure of the distal ulnar physis in a similar time period to other methods. Lateral deviation of the foot was first noted two weeks post-implantation of the screws in three of the four dogs, and by three weeks post-implantation all dogs were showing mild lateral deviation. This time interval coincides well with the literature.

In the 4.5 week time interval post-epiphysiodesis, three dogs developed more severe elbow abnormalities (subluxation) relative to radial curvature (Fig. 5), while one dog developed minor elbow subluxation and more severe signs referable to radial curvature (Fig. 12). It is of particular interest to find after distal ulnar physeal retardation that some dogs will develop more elbow abnormalities while others will develop more curvus and lateral deviation of the distal radius. In one review of 14 cases of premature closure of the distal ulna, nine of the fourteen dogs developed moderate to severe elbow subluxation while the other five developed slight or no elbow subluxation. Of the dogs with moderate to severe elbow subluxation, three of the dogs exhibited only slight radial curvature and lateral deviation, where as the other six developed moderate to severe radius curvus and lateral deviations. The 14 dogs ranged in age from 3-5 months, and there did not appear to be any correlation between the age at which closure occurred and development of elbow subluxation versus radius curvus.[40] In another review of 58 cases of early closure of the distal ulnar physis, only seven dogs developed abnormalities of the elbow.[35] There was no specific information concerning age or severity of curvature or subluxation. In an experimental study on effects of varying amounts of ulnar growth retardation, two dogs with 53% reduction of ulnar growth developed elbow subluxation and radial curvature, and progressed similarily until 56 days post-irradiation at which time subsequent progression differed. One dog expressed subsequent effects in the distal radius where marked curvature of the bone developed. In the other dog, subluxation of the elbow continued until 84 days post-irradiation at which time the degree of elbow subluxation remained constant. In this dog the curvature of the distal radius was less marked and lateral deviation of the elbow more marked than the former dog.[4]

From information available in the literature, no speculation or comments have been raised as to the pathogenesis of one deformity preceding or being more dominant than another. It does not appear to be related entirely to age, as evidenced by the literature. Although, the earlier physeal closure occurs the more potentially severe growth deformities will be of either type. The size and weight of the dog could have some bearing on development of one deformity over another, but again this was not consistent in the literature nor in the present study. Alteration of radial physeal growth could affect the development of deformities. A relative undergrowth of the distal radial physis with an accelerated proximal radial physeal growth could produce increased subluxation of the elbow while decreased curvature of the distal radius, whereas if the situation were reversed the opposite effect could occur. The specific nature or type of injury could have varying affects on the respective physes. One other consideration would be the relative strengths or lack of strengths of the interosseous ligament proximally and the radio-carpal joint attachments distally. An unyielding interosseous ligament could disrupt proper synchronous movement between the proximal radius and ulna much like a synostosis or cross-pinning the radius to the ulna.[1,29] A tightly bound distal radioulnar attachment could, on the other hand, limit growth from the distal radius to the point of only anterior bowing and outward rotation. The actual pathogenesis is probably related to a combination of the preceding considerations and varies with the individual.

Several dissimilarities emerged when comparing the effects of distal ulnectomy on the two groups of dogs. Carpal stability, as eluded to earlier, was not found to be a problem with dogs of Group I, whereas, palmar stability of the ulnectomied limbs of dogs in Group II was found to be decreased post-ulnectomy. Three of the four dogs demonstrated a moderate to marked dropping of the carpus throughout the study post-ulnectomy (Fig. 11). Palmar stability in these dogs was felt to be compromised secondary to stretching of the palmar supporting structures prior to distal ulnectomy from the effects of distal ulnar physeal closure, but more importantly, added stresses were placed on the ulnectomied limb of dogs in Group II. The left limb became rapidly more deformed and less functional as time progresses so that by four to six weeks post-ulnectomy, the ulnectomied limb became the dominant weight bearer and by 11 weeks post-ulnectomy had to assume total weight bearing. In contrast, one dog of Group II developed moderate to marked stretching of the palmar supporting structures pre-ulnectomy which improved to a mild dropping of the carpus post-ulnectomy. This dog was not forced to bear added stresses on the ulnectomied limb because the left leg was much slower developing growth abnormalities than the other dogs of Group II and remained a functional limb until 15 to 16 weeks post-ulnectomy.

The dogs of Group II were more reluctant to bear weight on the ulnectomied limb in the post-ulnectomy period than dogs of Group I. This was assumed to be caused by the relative lack of palmar stability that the Group II dogs exhibited in contrast to the Group I dogs. Personality of the groups may also have been a factor. The dogs of Group I were always more active and less timid as compared to the Group II dogs. The latter fact may have some bearing on why four dogs of Group I developed distal radial physeal complications, while this was not a finding in dogs of Group II. Without prior knowledge of what occurred in Groups I and II, distal radial physeal complications would have been expected more in dogs of Group II due to the added stresses placed on the distal radius as previously discussed. Dogs of Group II were kept in splints two weeks as compared to three weeks for Group I. Thus less stress protection occurred and being less active the Group II dogs stressed the ulnectomied limb less.

Correction of elbow subluxation occurred post-ulnectomy in all dogs of Group II. Within 24 hours postoperatively, elbow subluxation in one dog was noted to have improved considerably, while another dog with mild elbow subluxation was noted to be normal radiographically. Radiographs taken two weeks post-ulnectomy revealed all ulnectomied limbs to have normal elbow conformation and to have improved from the pre-ulnectomy period, whereas elbow subluxation and anterior radial curvature became more pronounced in the unoperated limbs (Figs. 5 and 6). In the subsequent study period, the ulnectomied limb improved but retained a mild anterior radial curvature and slight posterior radiocarpal subluxation.

The radiographic changes in the unoperated legs progressed more rapidly until 13 weeks post-ulnectomy (17 weeks post-epiphysiodesis) when slowing occurred. The radiographic changes noted correspond closely to previously reported changes.[4,5,31,35] Increased radial and ulnar cortical thickening has been previously reported in association with distal ulnar physeal closure as produced by irradiation of the physis.[5] In that report, ulnar thickening was localized to the caudal cortex. In the present study ulnar cortical thickening occurred along the cranial cortex in all dogs. I would not think lag screw fixation of the distal ulnar physis would alter stress lines in the ulna.

Physes of the left radius, as a general rule, closed before physes of the right radius, with all left proximal radial physes closing prior to the right. In two dogs (dogs 1,3), the left proximal radial physis closed eleven to twelve weeks earlier than the corresponding right physis. These two dogs also had the most severe radiographic, clinical, and gross lesions associated with the elbow of the four dogs. This would suggest that early physeal closure resulted secondary to the excessive pressures placed on the proximal radial physis during retardation of radial growth and abnormal articulation secondary to distal ulnar subluxation.

Lengthening of the right ulna post-ulnectomy occurred in all dogs of Group II similar to dogs of Group I with the length varying from eighteen to twenty-nine millimeters. The medullary cavity appeared radiographically to continue distally with lengthening. Osseous tissue distal to the osteotomy site was not noted in any of the dogs.

Gross lesions of the right elbow were limited to the distal lateral one half of the trochlear notch where mild to moderate erosion of articular cartilage occurred (Fig. 14). This would be an expected finding due to improper articulation secondary to ulnar subluxation prior to ulnectomy. Abnormalities of the right carpus of three dogs were limited to erosion of the lateral aspect of the ulnar carpal bone caused from lack of articulation with the styloid process. This was a consistent finding in Group I ulnectomied limbs as well.

Gross changes associated with the left elbow were similar in all dogs but of a more advanced state in dogs 1 and 3. Gross lesions described in the literature associated with distal ulnar physeal closure have been from studies of shorter duration, and where the major emphasis was placed on radiographic or histological changes.[4,6] The changes noted in this study coincide closely with lesions described in the elbow of dogs with the radius cross-pinned to the ulna.[29] In both studies, marked, long term elbow subluxation resulted in extensive degenerative changes of the proximal radius, trochlear notch and anconeal process of the proximal ulna, and distal humerus. The degenerative lesions associated with the trochlear notch appeared to be related to loss of articular contact with the distal humerus. As stated earlier, this appears to be associated with lack of proper nutrition being transmitted to the articular cartilage from the synovial fluid and subchondral bone by normal articular contact and movement.[11,14,22] The degenerative changes of the proximal radius, anconeal process, olecranon, and distal humerus appeared to be related more to excessive mal-aligned articular contact and ligamentous distractions.

The gross changes noted in the left carpal joints were again more advanced in dogs 1 and 3 with all carpii demonstrating posterior subluxation and lateral angulation with respect to the distal radius and ulna. One dog had mild articular erosion along the anterior aspect of the radial carpal bone from improper contact.

Of interest is the mild lesions associated with the right carpus, although marked palmar dropping occurred with moderate palpable joint laxity and crepitace. The only articular erosion noted other than that associated with the ulnar carpal bone was mild erosion of the lateral aspect of the radius and diffuse fibrin spots over the anterodorsal radial carpal bone in one dog. It is presumed that joint laxity of longer duration or of increased severity must occur before significant osteoarthrosis of the carpus occurs.

Histopathology of the elbows of unoperated forelimbs demonstrated lesions consistent with advanced non-inflammatory degenerative joint disease as described in the literature.[22,24] Sections taken from the elbow joint of ulnectomied limbs demonstrated mild to advanced cartilage changes associated primarily with the distal lateral one half of the trochlear notch. Lesions in this area have been described previously.[29]

Summary and Conclusions

Twelve dogs, 13-14 weeks of age, were used to study: 1) the effects of distal ulnectomy on young growing dogs, and 2) the benefits of distal ulnectomy as used to correct premature distal ulnar physeal closure. The study was divided into two groups. Eight foxhounds, 13 weeks of age, were used to study the effects of distal ulnectomy on one forelimb as compared to the control opposite forelimb. Monitoring of radial growth and development of growth abnormalities was conducted with bi-weekly radiographs initially and followed monthly until 25 weeks post-ulnectomy. At termination, necropsy was performed to evaluate gross changes of the antebrachium including the elbow and carpal joints. The second group was composed of four afghan-shepherd mix 14-week old dogs. Distal ulnar epiphysiodesis was performed bilaterally and allowed to produce clinical and radiographic abnormalities, at which time distal ulnectomy was performed on one forelimb. The opposite forelimb served as a comparison for the corrected limb. Monitoring was conducted radiographically, by clinical observation, gross pathology, and histopathology at termination.

The effects of distal ulnectomy varied somewhat from Group I to Group II. Lack of carpal stability was not found to be a problem in Group I dogs, whereas it was in Group II dogs. Distal radial physeal growth abnormalities developed in 50% of the Group I dogs, whereas no radial abnormalities were encountered in Group II. Shortening of the ulnectomied limb resulted from decreased radial growth in Group I. The only shortening of significance was associated with distal radial physeal disruption in four dogs. No measurements of growth were attempted in Group II due to lack of a normal control. Extreme irreversible growth deformity occurred in the un-operated leg of Group II dogs, whereas correction of developing growth aberrations occurred in the ulnectomied limb with palmar carpal laxity being the major drawback.

It has been shown that removal of the distal ulna with transposition of the styloid process will result in correction of early effects produced by premature closure of the distal ulnar physis, and that if properly performed will not result in untoward effects.[10] Two other reports have shown that transposition of the styloid process was not necessary and further substantiated the fact that correction of early changes associated with premature closure occurs without complications associated with the procedure.[12,25] In evaluating the present study, I believe distal ulnectomy to be a viable procedure for the correction of early changes associated with distal ulnar physeal closure, but it is not without potential postoperative complications and does not offer any advantages over distal ulnectomy with retention of the styloid process. In the latter procedure the ante-brachiocarpal joint is not disturbed, and lateral and palmar ligamentous support are maintained.

The effects produced by distal ulnar physeal closure are going to be dependent upon the age of the animal and amount of growth potential remaining in the physis, and the degree of deformity at presentation will determine treatment rationale. If angular deformities are severe and presentation is late in the growth period, corrective osteotomy alone or in conjunction with distal ulnectomy may be indicated.

As in all studies, new ways of approaching the problem or related findings altering the approach are discovered. More studies are needed for further evaluation of complete distal ulnectomy. Distal ulnar physeal closure should be produced in one leg only of two groups of dogs. One group would be corrected by complete removal of the distal ulna, while the other group corrected leaving the styloid process. The results of the two procedures could then be compared as to efficacy of correction and untoward effects secondary to the procedure. Other studies designed to determine the pathogenesis of elbow subluxation versus radial curvature would also be beneficial.

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Figure 1. Radius and ulna of a normal fourteen week old dog, lateral view.

A. Proximal radial epiphysis
B. Proximal radial physis
C. Proximal radial metaphysis
D. Radial diaphysis
E. Distal radial metaphysis
F. Distal radial physis
G. Distal radial epiphysis
H. Proximal ulnar epiphysis
I. Proximal ulnar physis
J. Proximal ulnar metaphysis
K. Ulnar diaphysis
L. Distal ulnar metaphysis
M. Distal ulnar physis
N. Distal ulnar epiphysis

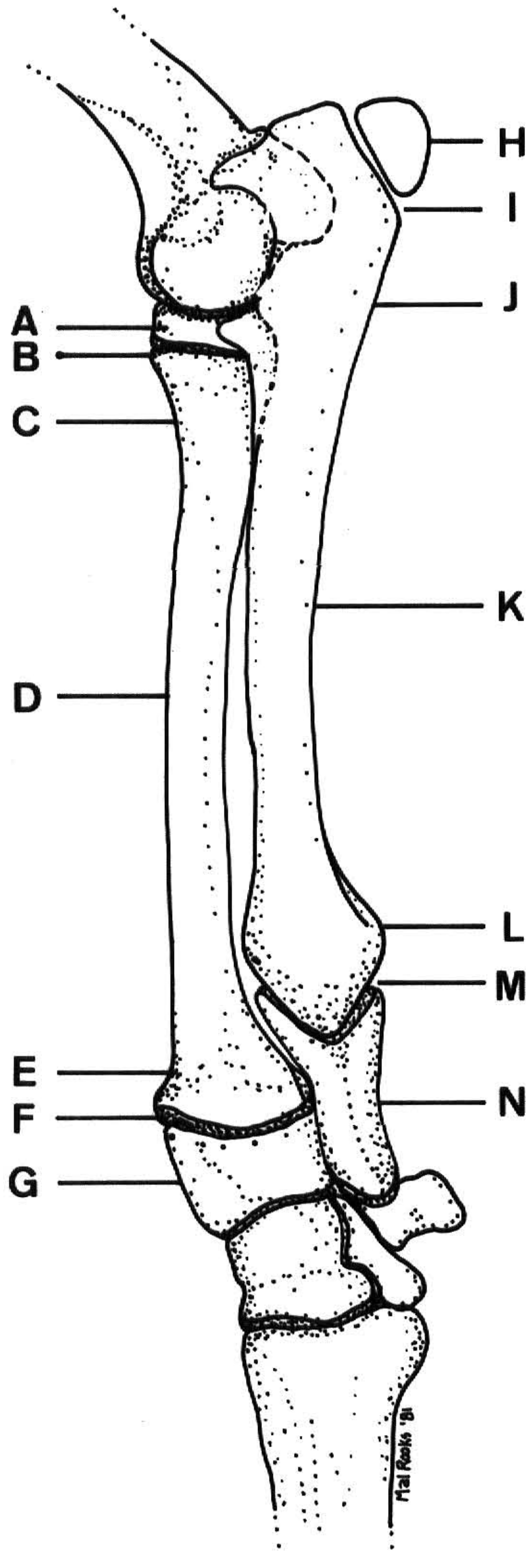

Figure 1

Figure 2. Radiograph of dog 1, Group II, 24 weeks post-ulnectomy, AP and lateral views; demonstrating advanced lesions produced by early closure of the distal ulnar physis.

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

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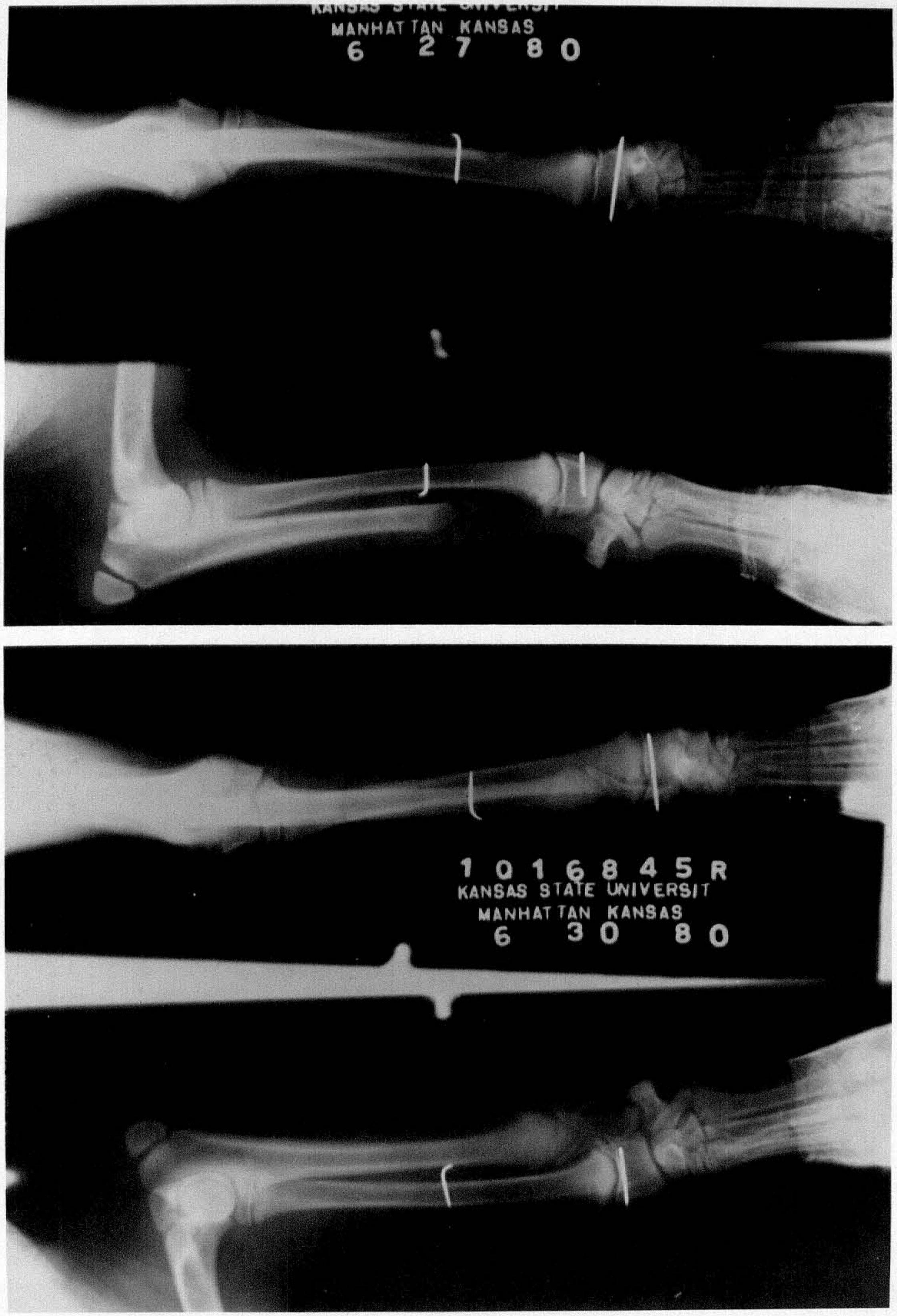
Figure 2

Figure 3. Radiographs of dog 5, Group I, left (A) and right (B) forelimbs immediate post-ulnectomy, AP and lateral views.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A

B

Figure 3

Figure 4. Graph of mean growth curve, Group I, left and right radial growth.

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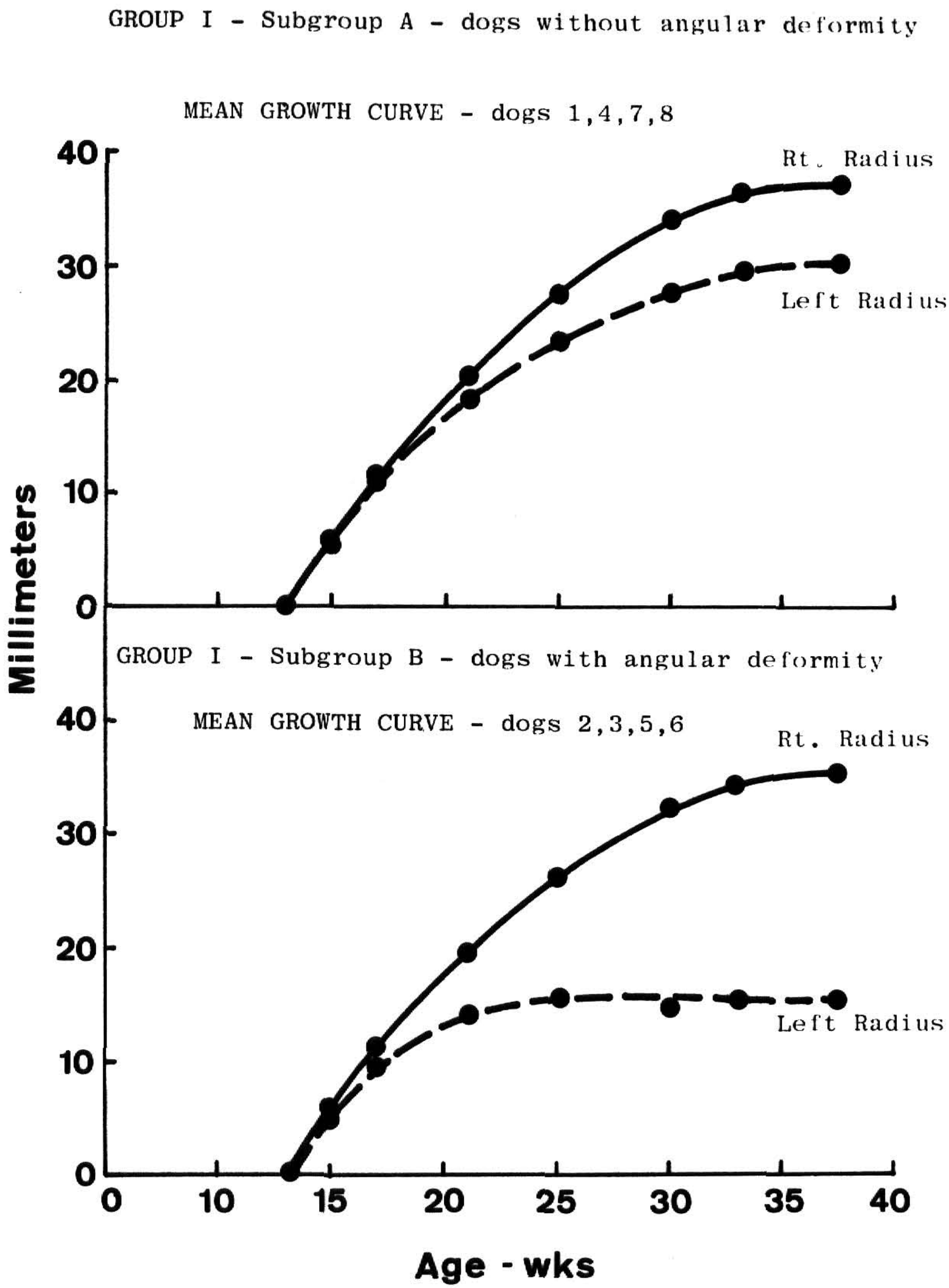

GROUP I - Subgroup A - dogs without angular deformity
MEAN GROWTH CURVE - dogs 1,4,7,8
Rt. Radius
Left Radius
GROUP I - Subgroup B - dogs with angular deformity
MEAN GROWTH CURVE - dogs 2,3,5,6
Rt. Radius
Left Radius
Millimeters
0
10
20
30
40
Age - wks

Figure 4

Figure 5. Radiographs of dog 3, Group II, 4.5 weeks post-epiphysiodesis - pre-ulnectomy demonstrating early changes associated with premature distal ulnar fusion.

Figure 6. Radiographs of dog 3, Group II, two weeks post-ulnectomy demonstrating correction of right elbow subluxation and worsening of left, uncorrected limb.

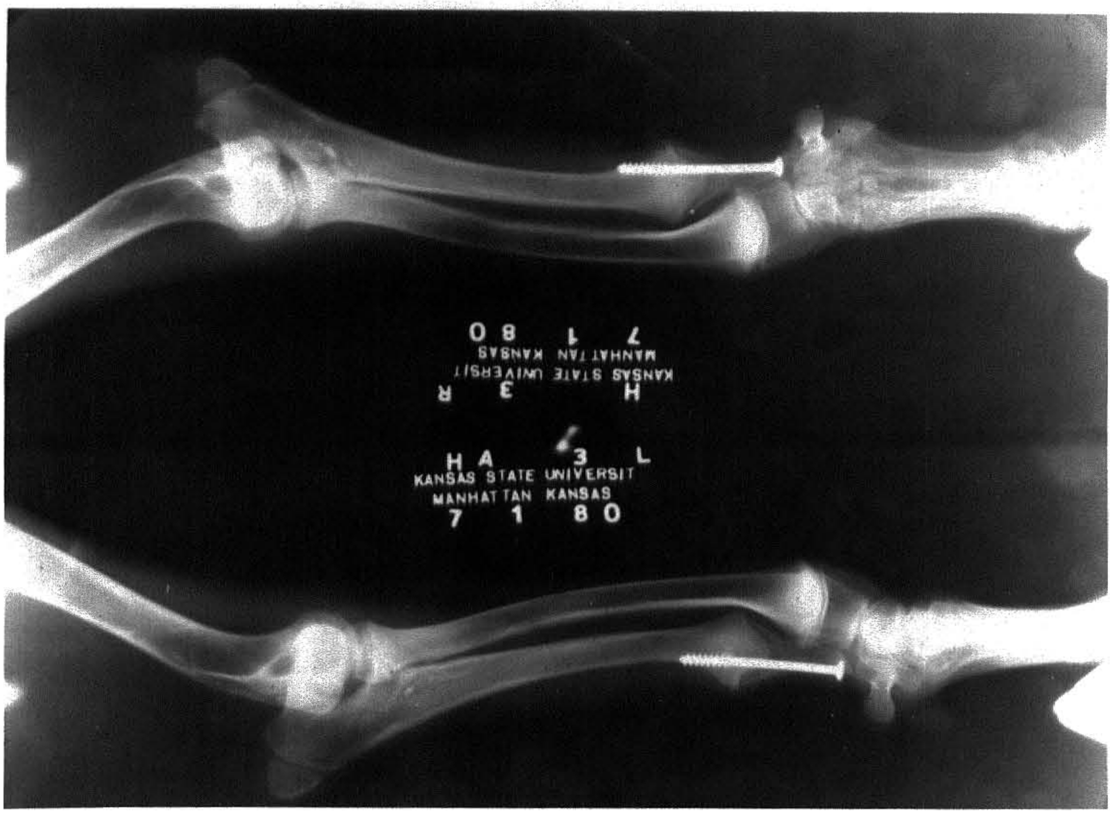

Figure 5

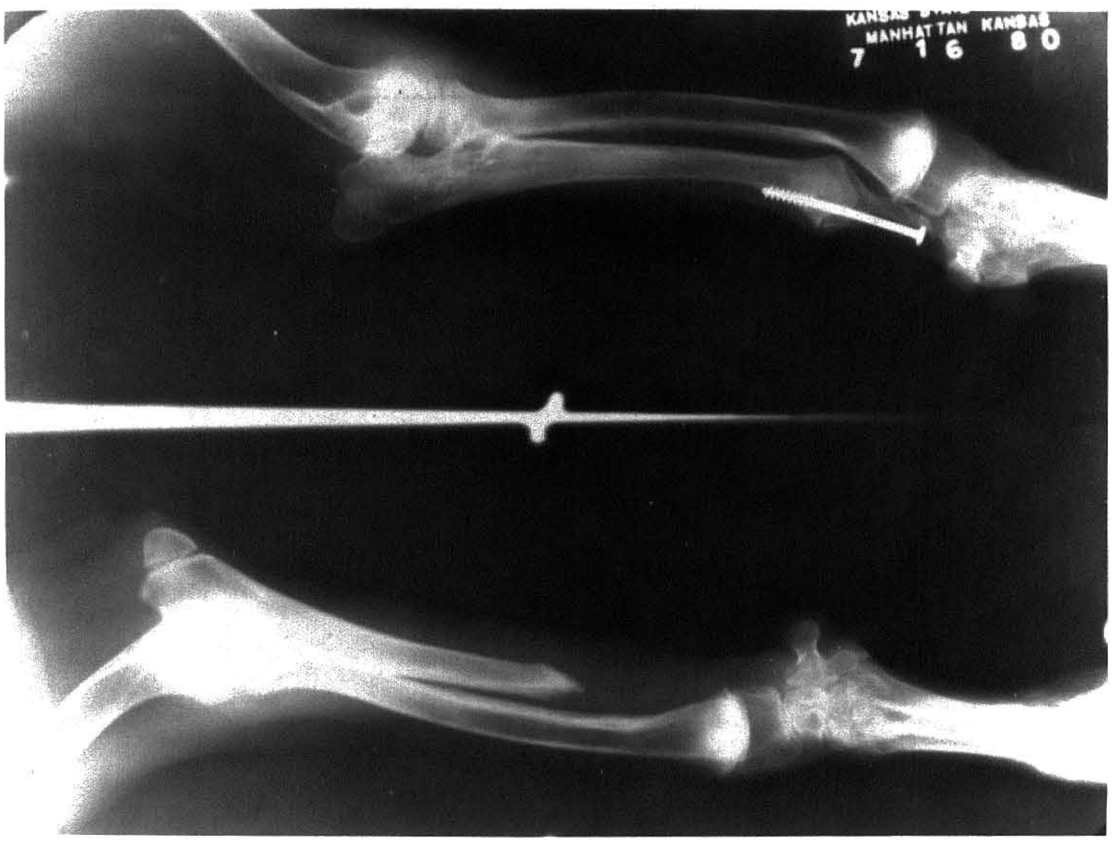

Figure 6

Figure 7. Dog 6, Group I, 25 weeks post-ulnectomy demonstrating angular deformity of distal radius and foot.

Figure 8. Dog 8, Group I, 25 weeks post-ulnectomy demonstrating lack of angular deformity of distal extremity.

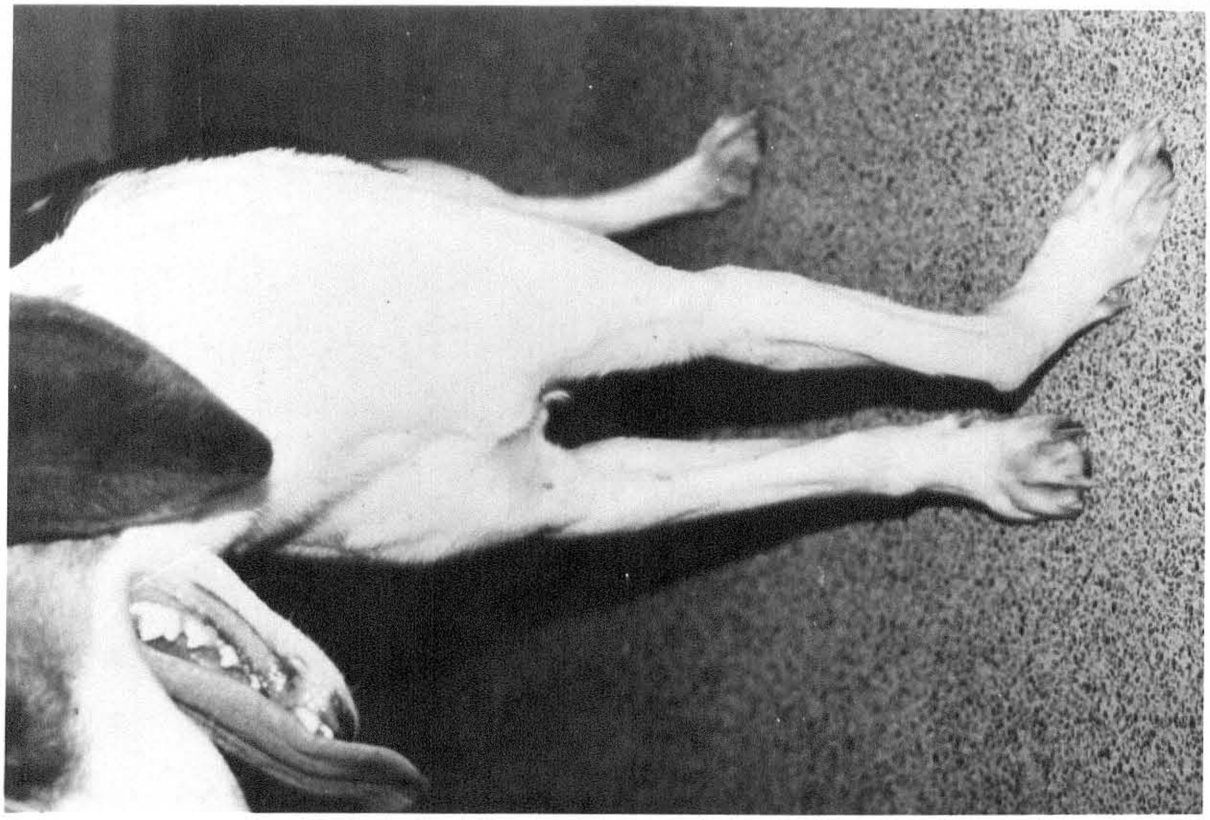

Figure 7

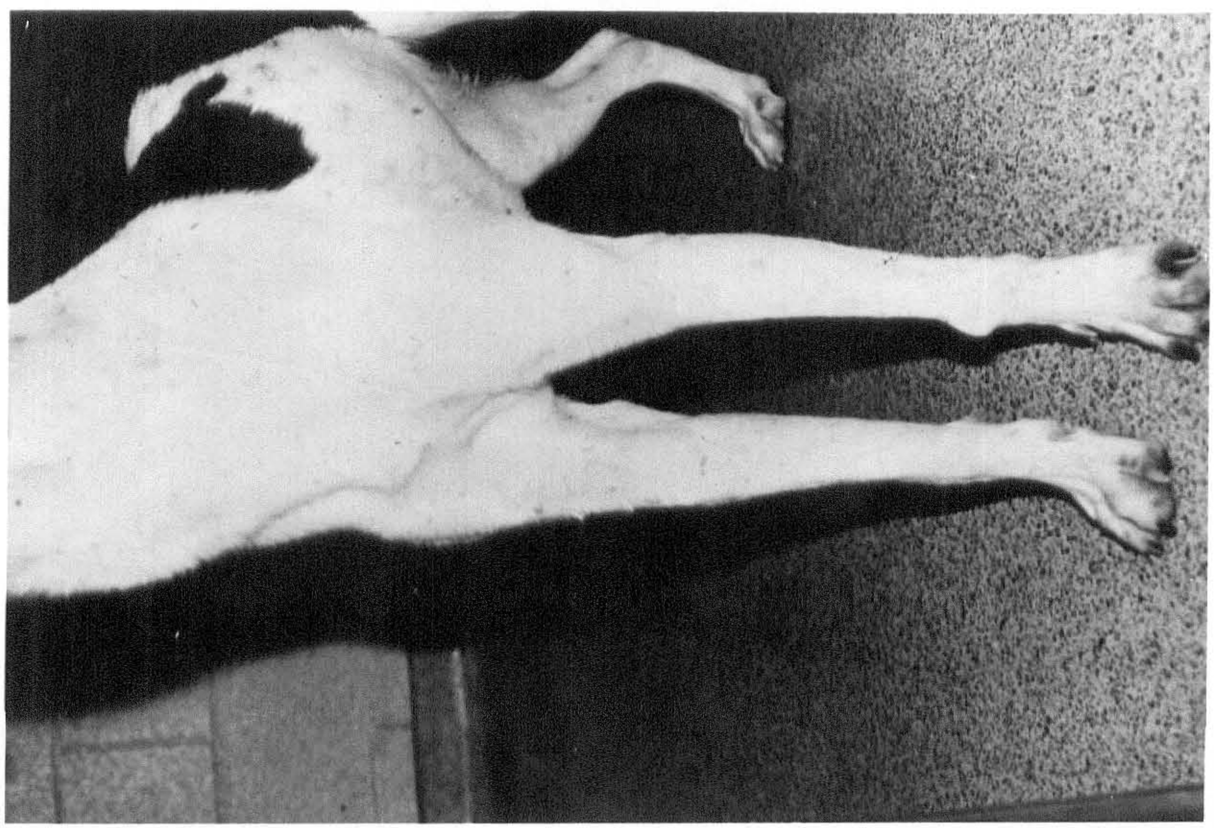

Figure 8

Figure 9. Radiograph of dog 5, Group I, carpal series eleven weeks post-ulnectomy demonstrating Type I physeal fracture.

Figure 9

Figure 10. Radiographs of dog 5, Group I, 25 weeks post-ulnectomy; A-control right leg, B-left ulnectomied leg with angular deformity.

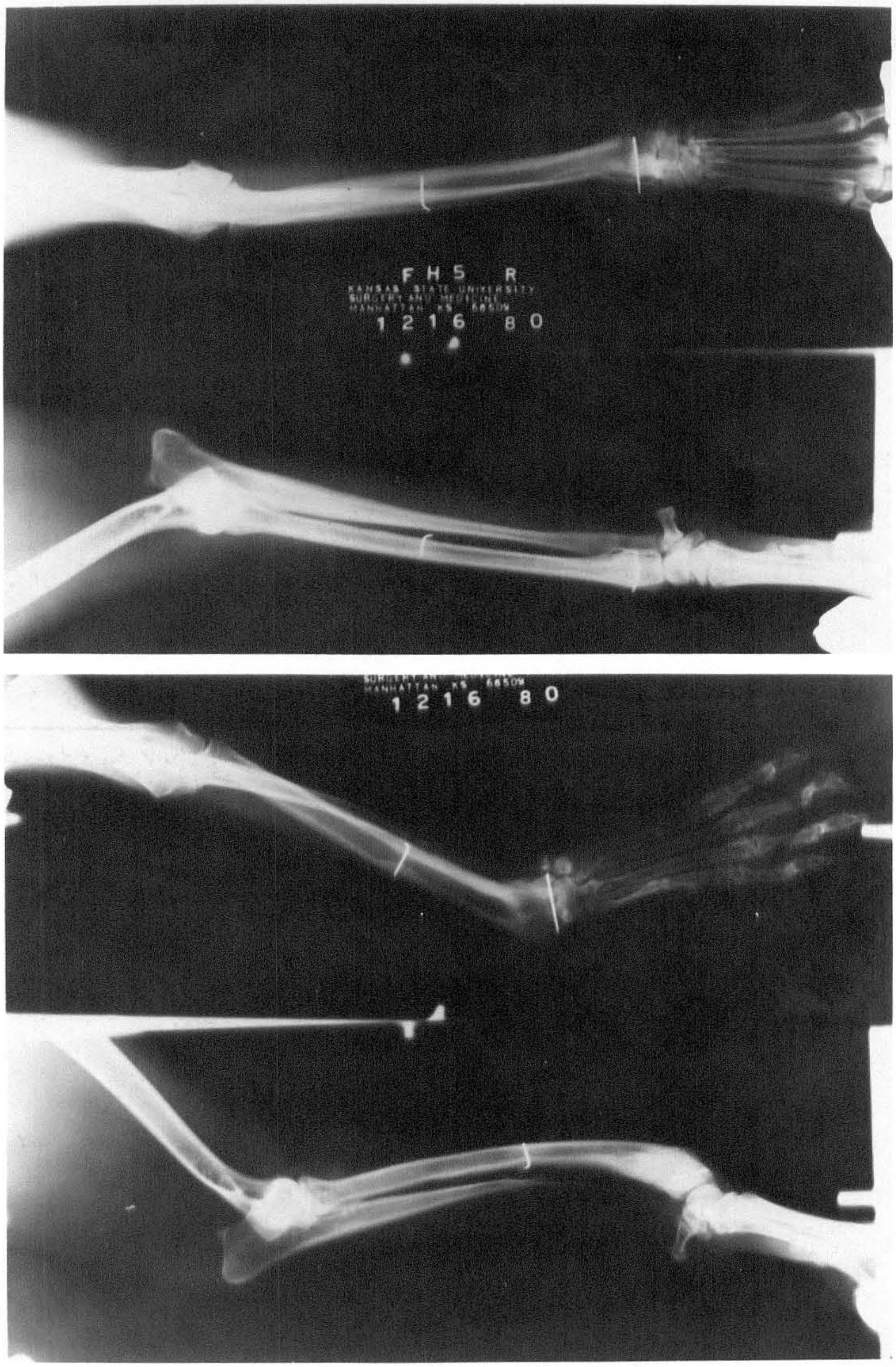

Figure 10

Figure 11. Dog 3, Group II, 24 weeks post-ulnectomy demonstrating palmar carpal laxity.

Figure 11

Figure 12. Radiographs of dog 4, Group II, 4.5 weeks post-epiphysiodesis/pre-ulnectomy demonstrating radial bowing and lateral deviation of right leg.


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Figure 12

Figure 13. Free ossicle (arrow) with in lateral aspect of un-operated elbow joint, dog 3, Group II. Severe degenerative joint disease associated with improper articulation and malformations.

Figure 14. Superficial erosion of distal lateral one half of trachlear notch (arrow), ulnectomied limb, dog 4, Group II, demonstrating relatively normal articular surfaces and anatomical relationships.

Figure 13

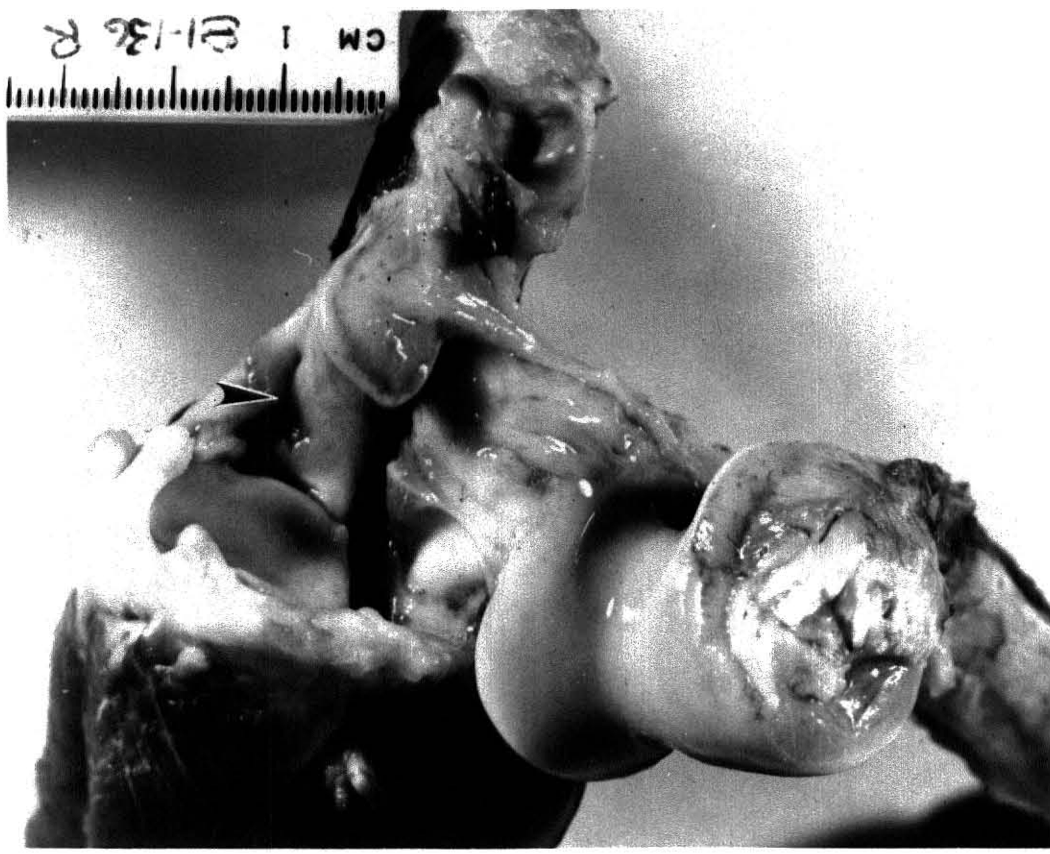
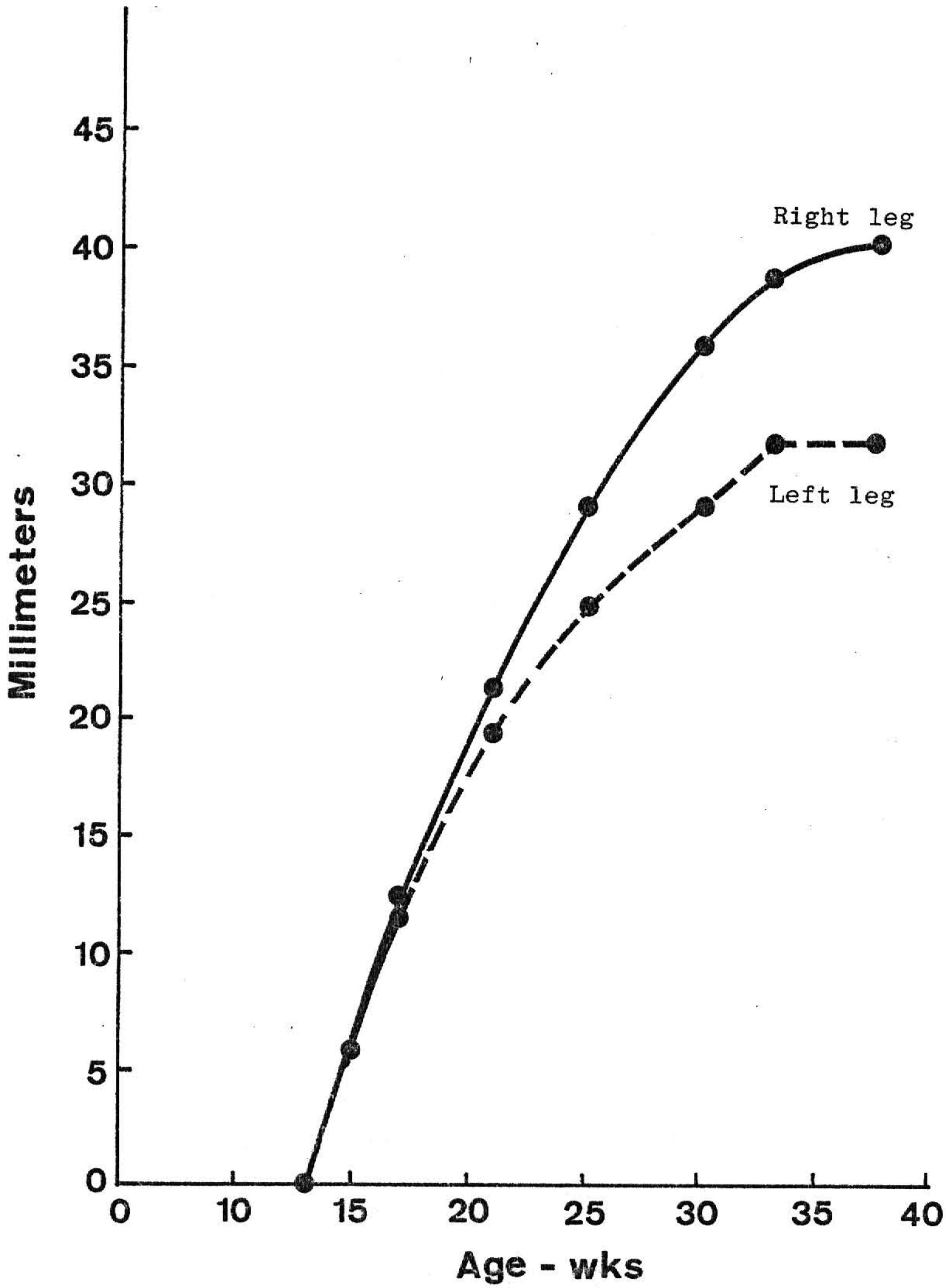


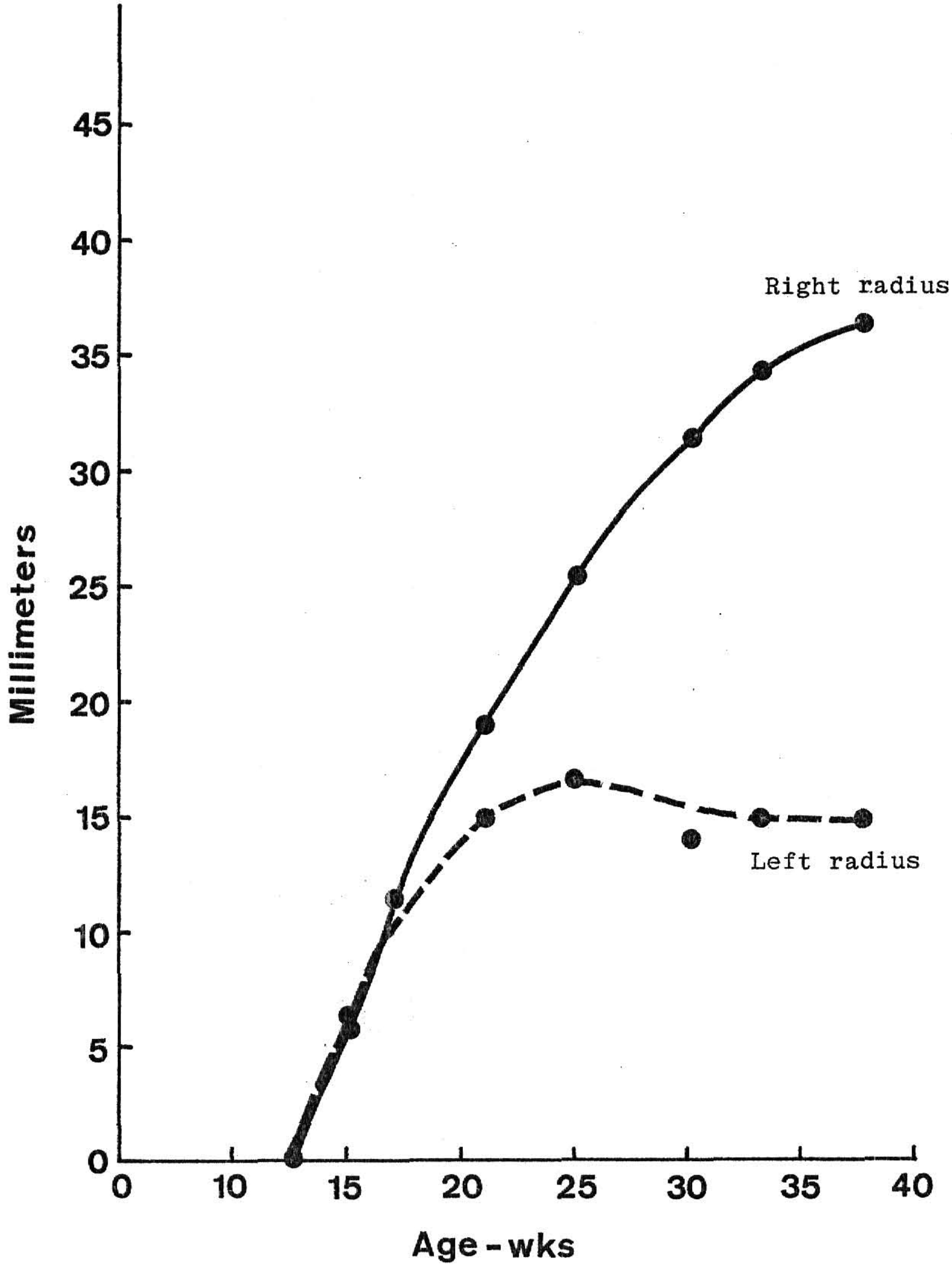
Figure 14

APPENDIX

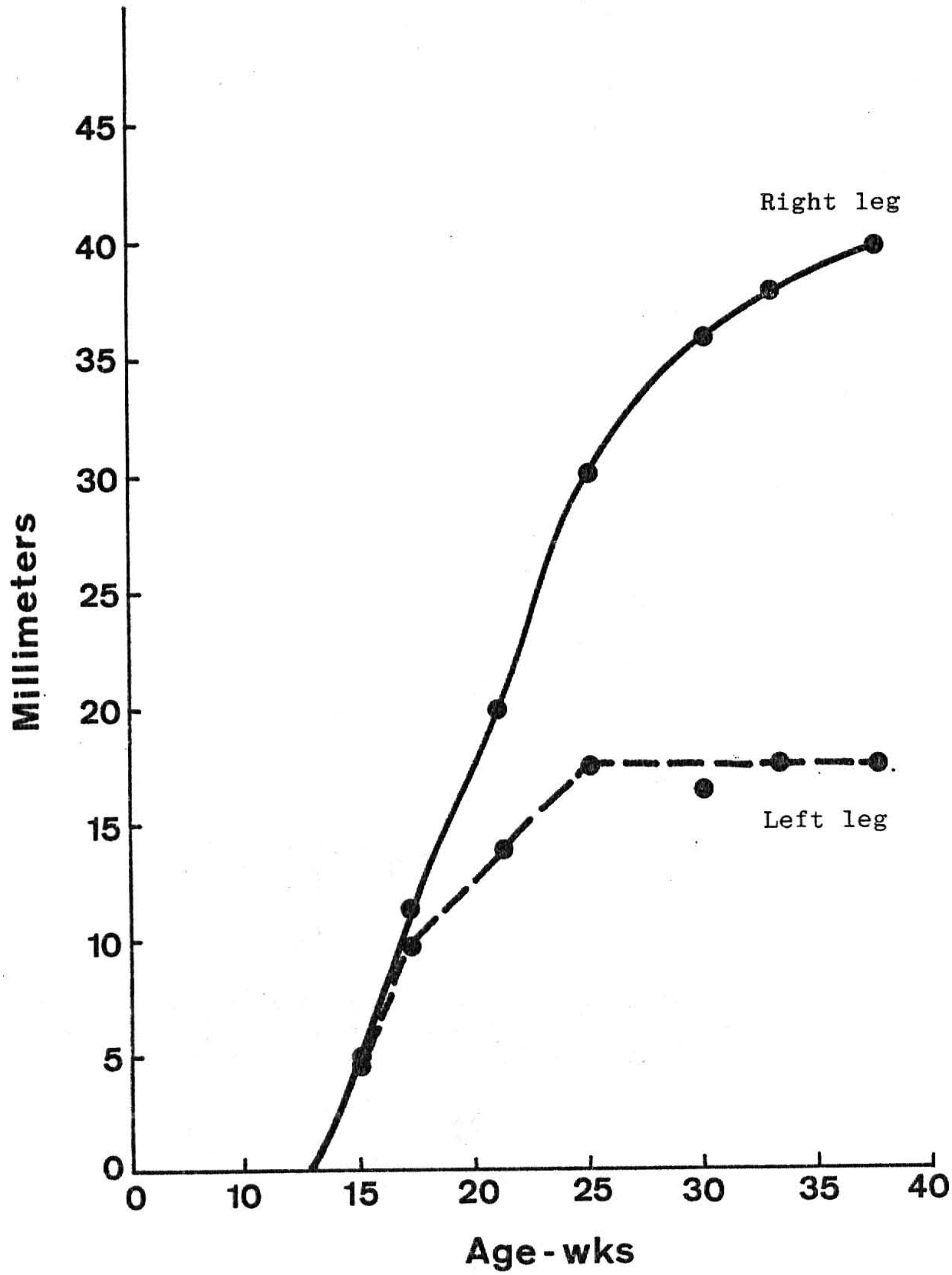
GROUP I - Growth curve - Left & Right Radius DOG 1



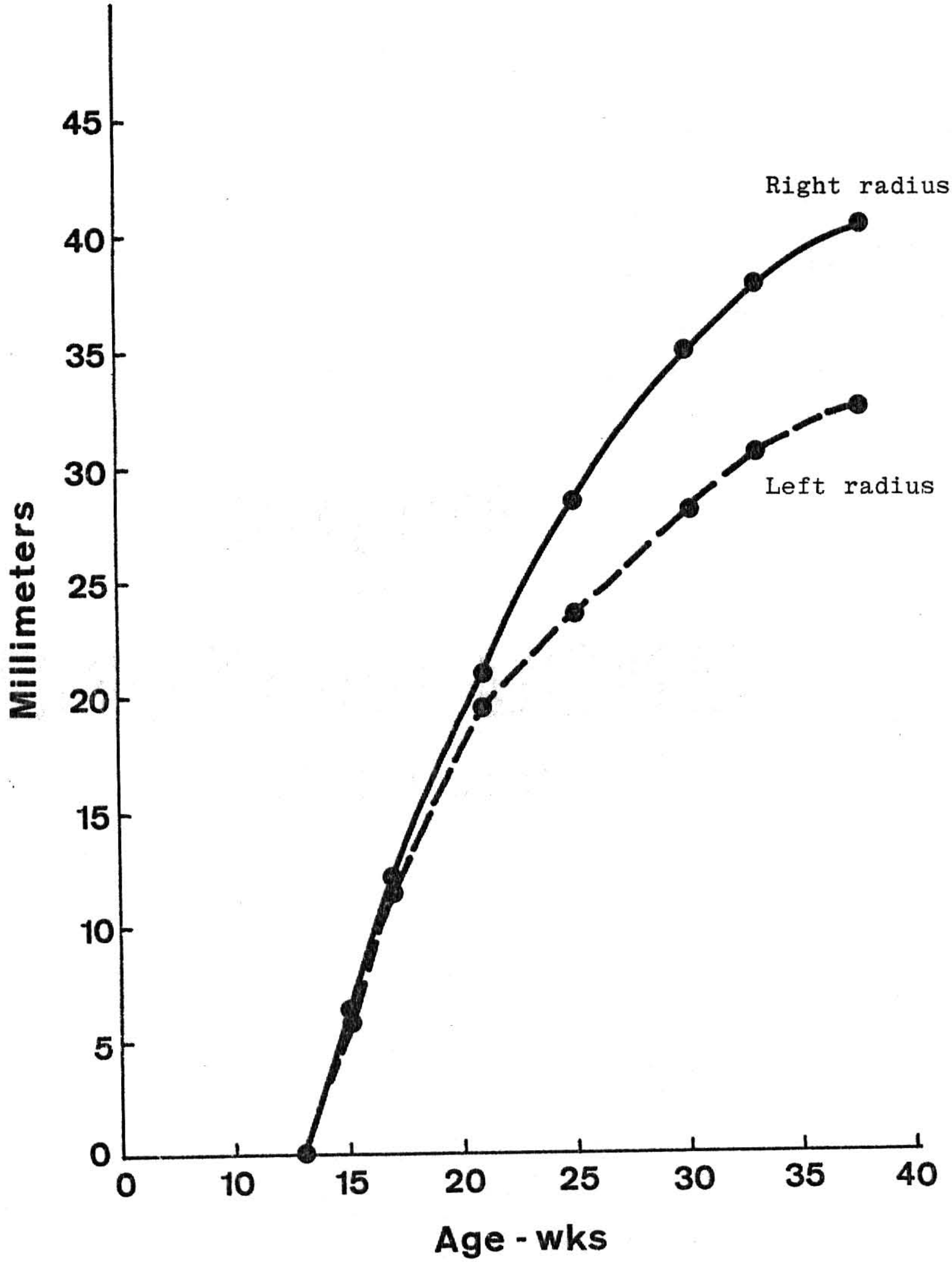
GROUP I - Growth curve - Left vs Right Radius DOG 2



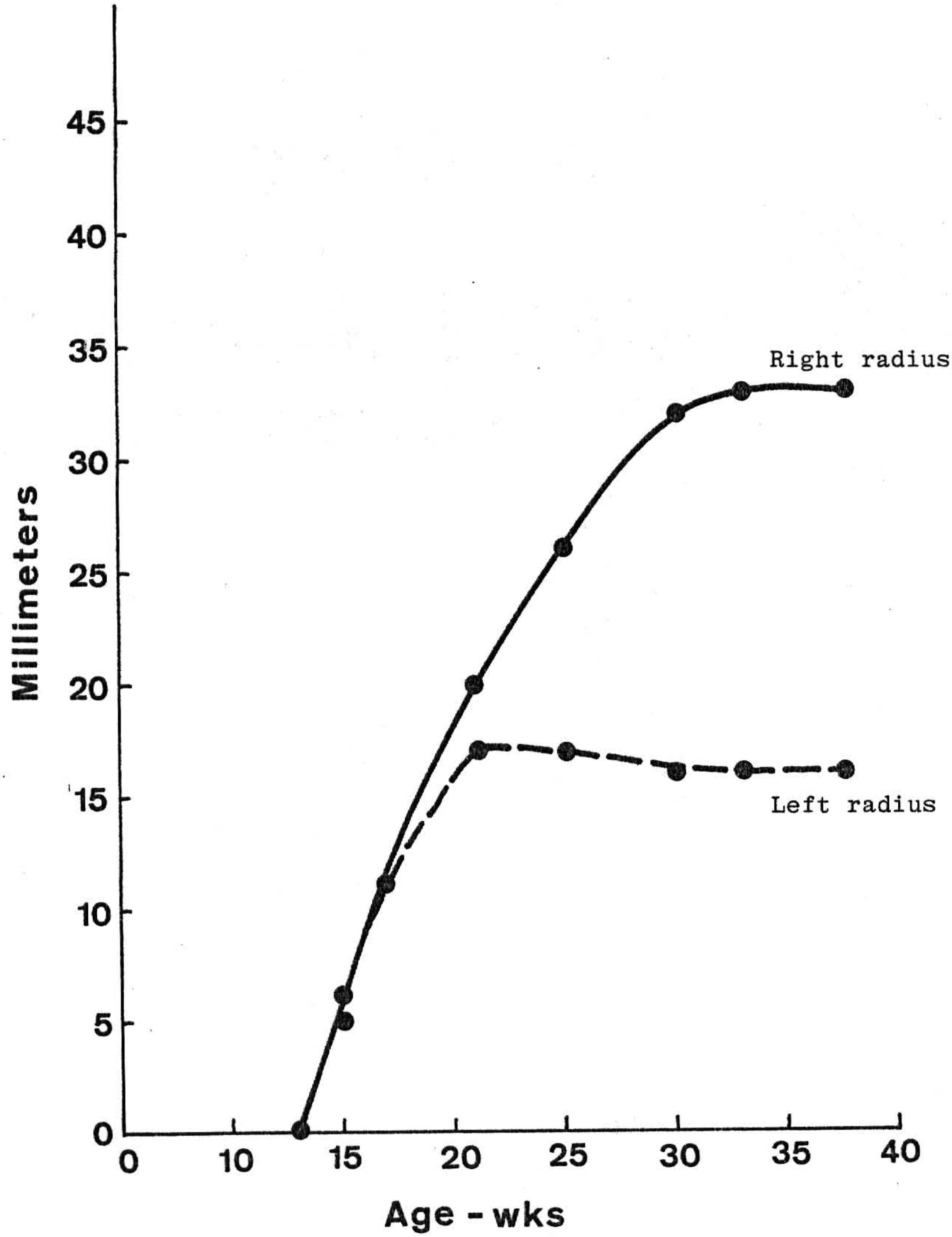
GROUP I - Growth curve - Left & Right Radius DOG 3



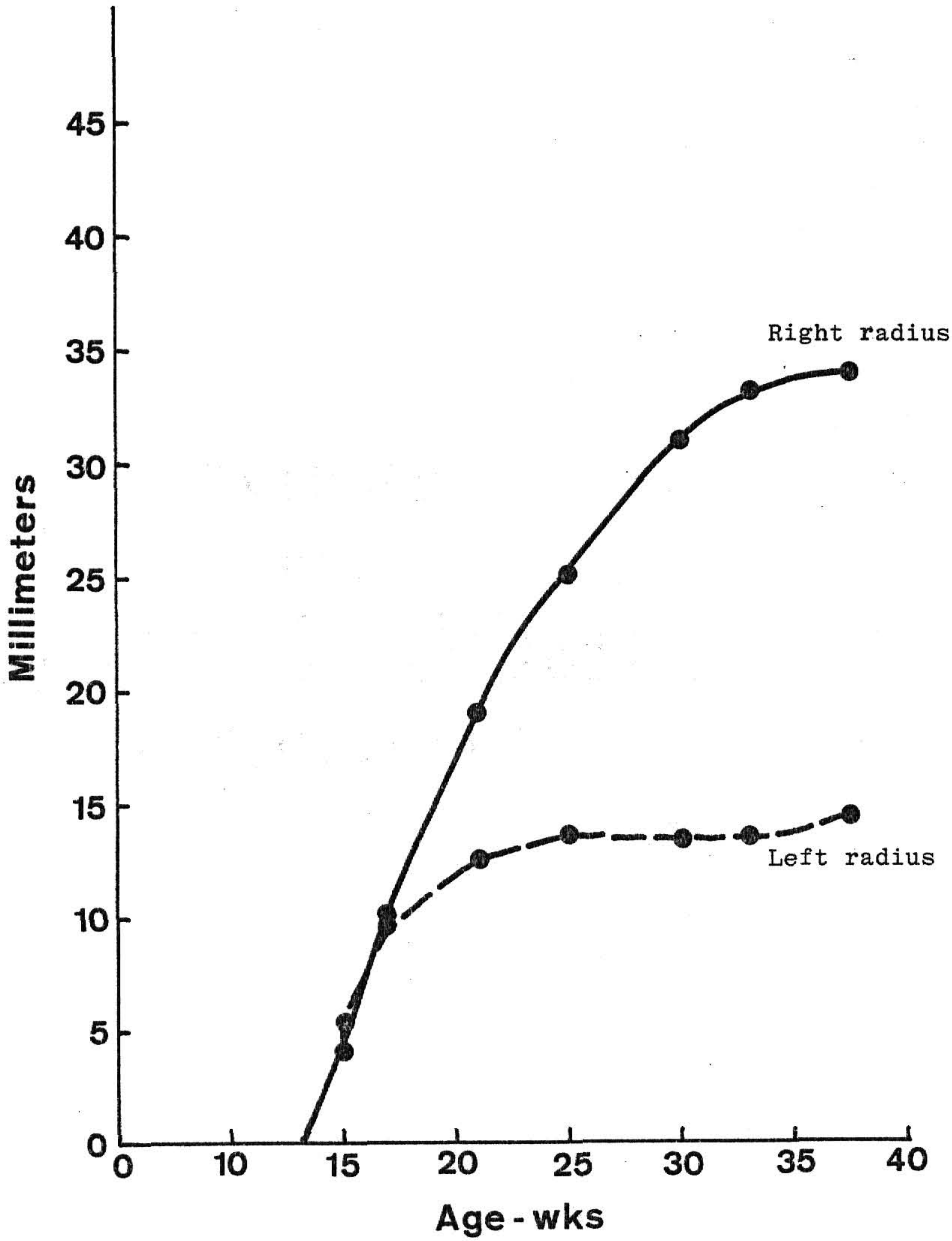
GROUP I - Growth curve - Left & Right Radius DOG 4



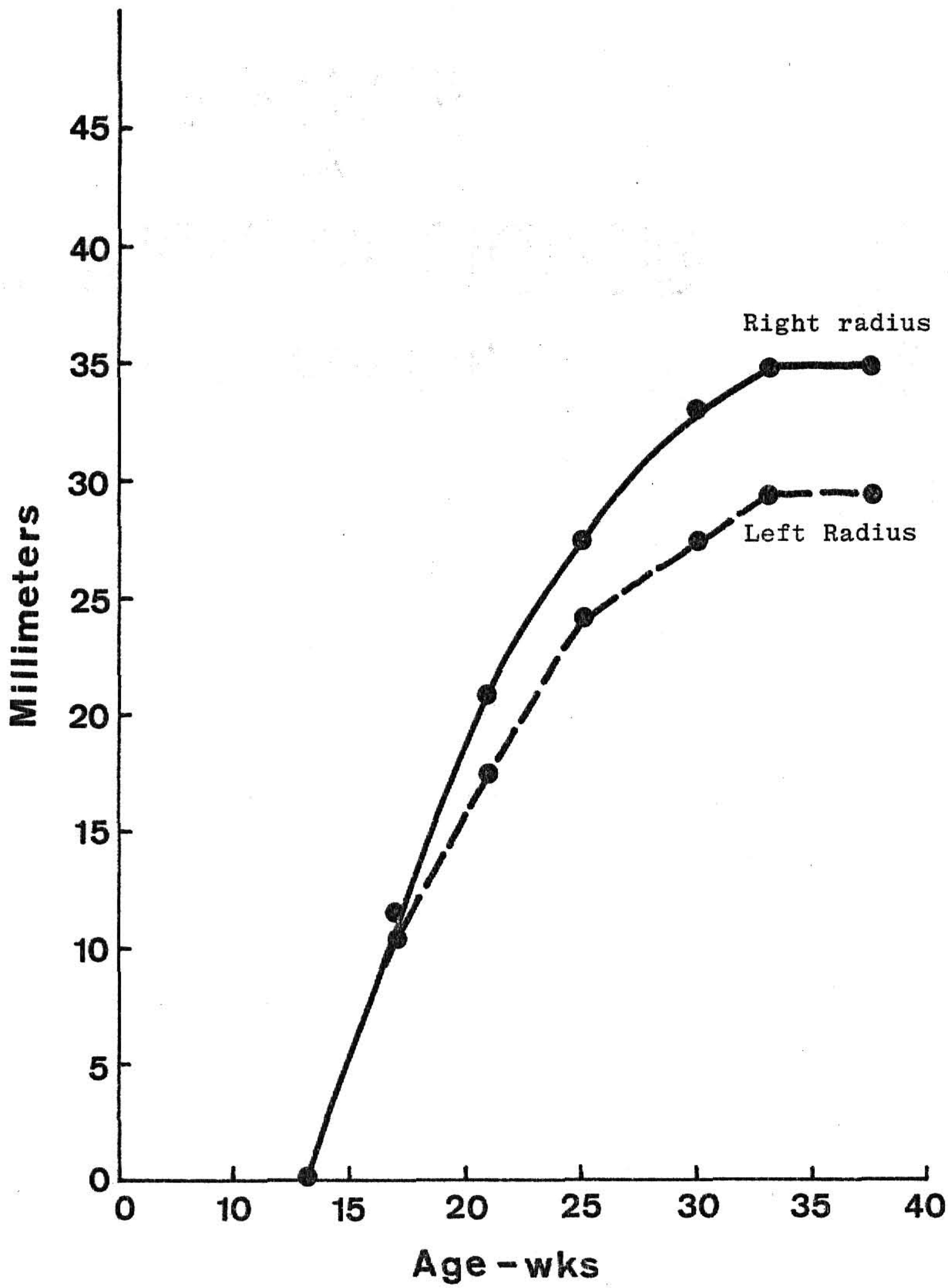
GROUP I - Growth curve - Left & Right Radius DOG 5



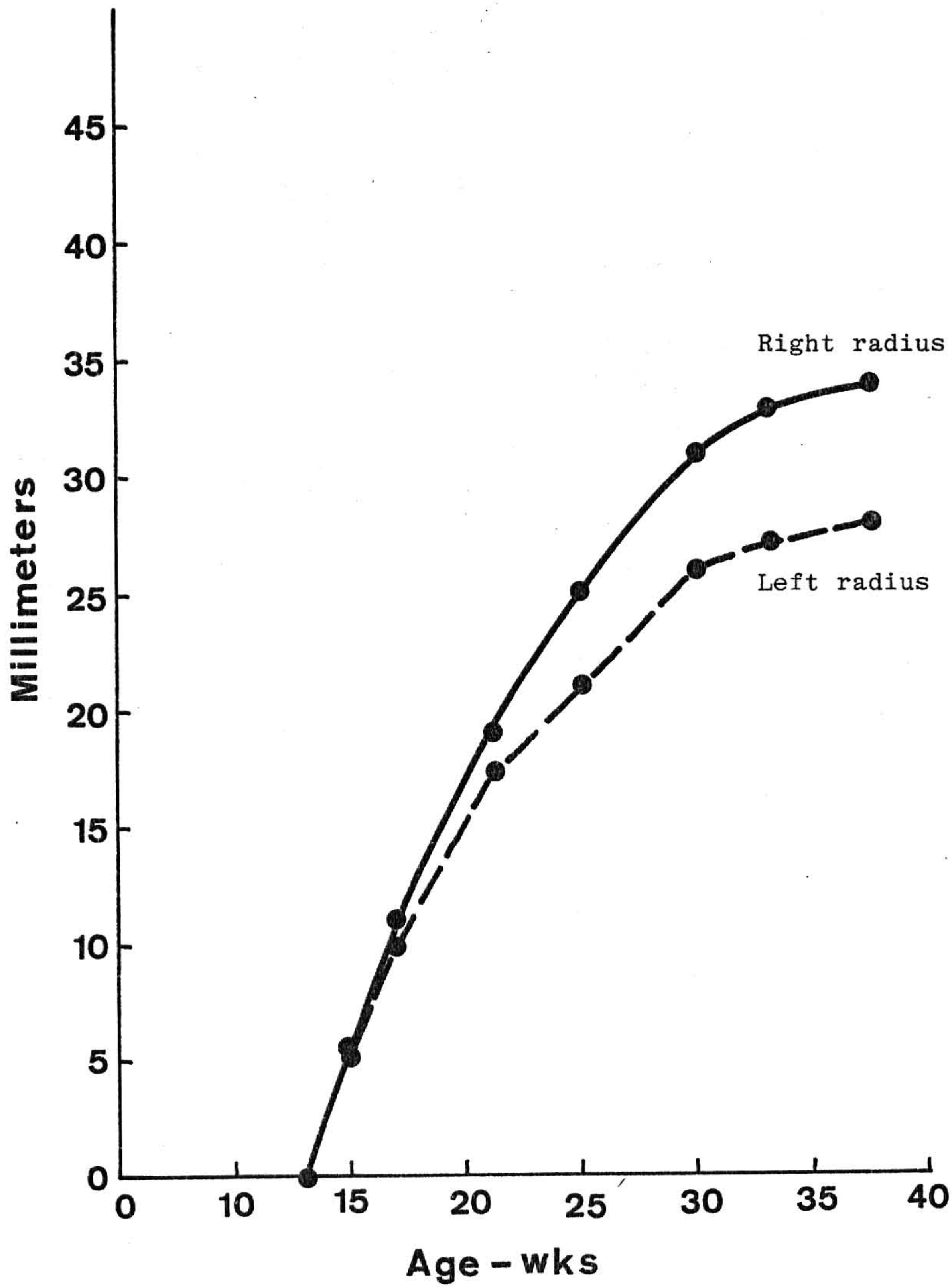
GROUP I - Growth curve - Left & Right Radius DOG 6



GROUP I - Growth curve - Left & Right Radius DOG 7



GROUP I - Growth curve - Left & Right Radius DOG 8



Distal Ulnectomy in Young Dogs

Affect on

Forelimb Growth and Carpal Stability

by

Richard J. Howard, D.V.M.

D.V.M. Auburn University, 1977

An Abstract of a Master's Thesis

submitted in partial fulfillment of the
requirements for the degree

Master of Science

Department of Surgery and Medicine
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Manhattan, Kansas

1981

Growth deformity of the forelimb due to early closure of the distal ulnar physis is the most common complication of physeal injury in the dog. With cessation of ulnar growth, retardation of radial growth occurs producing angular and rotational deformities. Abnormal articulation of the elbow and carpus occurs secondary to the deformities and may result in irreversible degenerative osteoarthrosis.

Over the years a number of surgical approaches have been utilized in the management of forelimb deformities with varying degrees of success. In this study, a two-fold approach was undertaken to study the affects of distal ulnectomy, first, on normal young growing dogs, and second, on dogs with premature closure of the distal ulnar physis. Twelve dogs were used in the study. Eight foxhound littermates, thirteen weeks of age, were used to demonstrate effects from distal ulnectomy in normal growing dogs (Group I), while four afghan-shepherd mix littermates, fourteen weeks of age, with iatrogenic bilateral premature closure of the distal ulnar physis were used to demonstrate distal ulnectomy as a corrective procedure (Group II). Both groups of dogs were followed radiographically and clinically post-ulnectomy, for untoward, as well as, beneficial effects. At the end of the study all dogs were euthanized and necropsied to evaluate gross changes of the elbow and carpal joints. Histopathological examination of the elbow joints of three of the afghan-shepherd dogs were performed.

During the course of the study effects of distal ulnectomy varied from Group I to Group II. Four of the eight dogs of Group I developed angular deformity of the distal extremity due to disruption of the distal radial physis of the ulnectomied limb. No radial abnormalities were encountered in Group II dogs. Lack of carpal stability was not found to be a problem in Group I dogs, whereas lack of palmar stability was encountered in Group II dogs. Shortening of the ulnectomied forelimb resulted from decreased radial growth in Group I dogs. The only significant shortening was associated with distal radial physeal disruption. Group II dogs demonstrated extreme irreversible growth deformity in the un-operated leg, whereas correction of developing growth deformities occurred in the ulnectomied limb with palmar carpal laxity being the major drawback.

In conclusion, distal ulnectomy can be a viable procedure for the correction of early changes associated with distal ulnar physeal closure, but is not without potential post-operative complications.