

# THE EFFECTS OF NUTRIENT ARTERY LIGATION ON THE DEVELOPMENT OF THE DISTAL ULNAR METAPHYSIS OF THE DOG

## Efectos de la Ligadura de la Arteria Nutritiva sobre el Desarrollo de la Metafisis Distal de la Ulna del Perro

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### ABSTRACT

A total of 18 dogs were used in this study. They were obtained from the Veterinary Hospital of the University of Pennsylvania, Comparative Cardiovascular Studies Unit and from a dog pound of the Veterinary Polyclinic, University of Zulia, Faculty of Veterinary Sciences. Ablation of the nutrient artery by ligation of the palmar interosseous artery was performed in 10 dogs; 6 one-month-old dogs; 2 two-month-old dogs; 2 three-month-old dogs. Radiographic examination of the forelimbs at a weekly interval was performed in these 10 dogs from one to six weeks postoperatively. The opposite normal front leg was used as a control. Six dogs were sacrificed at one month of age and arteriograms of the forelimbs were made. The radiographic changes observed during the first postoperative week were an increased in density and diameter of the distal ulnar metaphysis, increased width of the distal ulnar physis, and a decrease in length of the ulnar diaphysis. These radiographic changes were observed decreasing in severity during a period of five postoperative weeks. At six weeks postoperatively the distal ulna was similar to the control. Between 3 to 5 weeks postoperatively the metaphyseal density of the ulna was decreased and irregular. The decrease in metaphyseal density resulted from a wedge-shaped retained cartilaginous tissue core which extended proximally into the metaphysis. A diminished blood supply to that area was observed angiographically and histologically in all dogs. The changes observed in the distal ulnar metaphysis in histologic sections and radiographs are comparable to those observed in the distal metaphysis of the ulna in young giant dogs with retained enchondral cartilage. The radiographic and histological findings observed in this study suggests that the lesion observed in rapidly-growing young giant dogs in the distal ulna is due to a diminished blood supply to the

metaphyseal area. The study was designed with the specific objective to determine the effect on bone growth after ablation of the nutrient artery of the ulna of the dog.

**Key words:** Dog, ligation, nutrient artery, ulna.

### RESUMEN

Un total de 18 perros fueron utilizados en éste estudio. Éstos fueron obtenidos de la Unidad de Estudios Comparativos Cardiovasculares del Hospital Veterinario de la Universidad de Pennsylvania y de la Perrera de la Policlínica Veterinaria Universitaria de la Facultad de Ciencias Veterinarias de la Universidad del Zulia. La ablación de la arteria palmar interosea fue realizada en 10 perros. Seis (6) de un mes de edad, dos (2) de dos meses de edad, y dos (2) de tres meses de edad. El examen radiográfico semanal de los miembros torácicos fue realizado en estos 10 perros desde la primera hasta la sexta semana posterior a la cirugía. El miembro torácico contralateral fue utilizado como control. Seis (6) perros fueron eutanasiados al mes de edad y arteriogramas de los miembros torácicos fueron realizados. Los cambios radiográficos observados durante la primera semana post operativa fueron: incremento de la densidad y en el diámetro de la metafisis distal de la ulna, incremento en el grosor del cartílago de crecimiento distal de la ulna, y disminución de la longitud de la diáfisis ulnar. Éstos cambios radiográficos fueron observados disminuyendo en severidad, durante un período de cinco (5) semanas post operatorias. A las seis (6) semanas post quirúrgicas, la parte distal de la ulna fue similar al control. Entre las tres (3) y cinco (5) semanas post operatorias la densidad metafisiaria distal de la ulna estaba disminuida e irregular. La disminución de la densidad de la metáfisis resultó ser debido a un núcleo o segmento de tejido cartilaginoso en forma de cuña que se extendía proximalmente dentro de la metafisis. Una disminución del riego

sanguíneo hacia esa área fue observada angiográficamente e histológicamente en todos los perros. Los cambios observados en secciones histológicas en la metafisis distal de la ulna y en las radiografías son comparables con aquellas observadas en la metafisis distal de la ulna en perros jóvenes de raza gigante con retención de cartílago encondral. Los hallazgos radiográficos e histológicos observados en el presente estudio sugieren que la lesión observada en perros de raza gigante de rápido crecimiento en la ulna distal es debido a una disminución de riego sanguíneo en el área de la metafisis. Este estudio fue diseñado con el objetivo específico de determinar el efecto sobre el crecimiento óseo posterior a la ablación de la arteria nutritiva de la ulna del perro.

**Palabras clave:** Perro, ligadura, arteria nutritiva, ulna.

## INTRODUCTION

The long bone is a tube with thick walls of compact material. The ends, enlarged and covered with articular cartilage, are formed of spongy bone contained in a thin shell of compact bone. There is a central medullary cavity. Too often bone has been looked upon as an inert material and likened to a piece of wood to be sawed, planed, or nailed without thought given to its structure or physical properties. Bone is a living tissue which has a number of important functions [22, 23].

Bone is formed by osteoblasts and resorbed or destroyed by osteoclasts. Both of these cells are active within the skeletal system throughout life. During osteogenesis many factors affect the development of diseases such as achondroplasia, multiple epiphyseal dysplasia, rickets, and osteogenesis imperfecta [22, 23].

Most of the skeleton forms as a result of enchondral ossification. Enchondral ossification can be followed by observing the series of events that transform the cartilage mold of a limb into bone. In the various sites where bones are to form, the mesenchymal tissue differentiates into cartilage [22, 23].

The cartilage forms by genetic direction into specific cartilage models which are to become bones. The cartilage model increases in length and diameter by interstitial growth (cell division). Each bone model is surrounded by a close-fitting membrane, the perichondrium. The cells of the perichondrium form two ill-defined layers. The outer layer differentiates into fibroblasts which form collagen, the connective tissue sheath. The inner layer which surrounds the cartilage mold does not differentiate into fibroblasts. The nutrition is supplied by diffusion of fluids through the perichondrium [20, 23].

Diffusion of nutrients from the surrounding tissue through the perichondrium is an efficient and adequate method for a distance of 1-2 mm from either side of the cartilage mold. When the cartilage mold size exceeds the functional limits of diffusion, the cartilage cells become progressively separated at the center of the cartilage model. The separated

cells become hypertrophic and begin to degenerate. They develop vacuoles, and alkaline phosphatase appears in the surrounding matrix [20, 22, 23].

The matrix is formed by a mixture of highly reactive elements such as beta-proteins, collagen, and soluble polysaccharides, the best known of which are the chondroitins [20, 22, 24].

The nutrient artery, a single vessel, penetrates the perichondrium exactly at the center of the length of the bone model.

Calcification of the altered matrix begins at the periphery of the cartilage mold and progresses to a point near and always ahead of the vessels. Calcification allows vascular progression because it causes cell disintegration by cutting cells off from their nutrients. As a result of positive chemotaxis, peripheral vascular proliferation occurs toward the area of the cartilage mold occupied by degenerating chondrocytes and altered matrix [20, 22, 24]. A vascular front of branches from the nutrient artery advances into the calcified matrix, removing the hypertrophied degenerated cartilage cells and some of the calcified cartilage. As they continue to advance, the vascular tufts penetrate more hypertrophied cartilage cells [22]. Very soon, around the advancing vessels, the first osteoblasts are deposited against the calcified walls of the hypertrophied cavities occupied previously by degenerative chondrocytes and altered matrix. Preliminary bone formation occurs when the matrix or "osteoid" surrounding the osteoblasts becomes mineralized [20, 22, 23].

Bone, with its enclosed cells (osteocytes) is thus formed. By such a mechanism provisional bone is laid down along the shaft of the long bone cartilage model until the zone where the growth cartilage is to appear later is reached [20, 22, 23].

Growth deformities involving the dog's radius and ulna are common. Numerous authors [10, 11, 12, 15] report the clinical and radiographic signs and treatments of these deformities. These deformities include: premature closure of the distal ulnar and/or radial physis; retained hypertrophied enchondral cartilage of the distal ulnar metaphysis.

Several authors hypothesize a vascular insufficiency as the cause for these deformities [1, 7, 14, 15]. The deformities result in a complex orthopedic problem characterized by shortening of the leg, deviation of the distal aspect of the limb (a disparity in the length of the radius and ulna), and luxation and/or degenerative joint disease of the elbow and carpal joints.

Several investigators hypothesize a growth disturbance can result from a reduction of acceleration in the rate of enchondral bone formation in the physis of either the ulna or radius, while growth continues at a normal rate in the other bone. The end results are bowing of the radius and ulna and deformity of the carpus, metacarpus, and phalanges [14, 15].

Radiographic examination is essential for evaluation of these forelimb deformities.

Deformities of the forelimb of large and giant dogs have been reported [3, 11, 12, 15, 17].

The radiographic and histologic changes associated with the development of the bones of the forelimb in the giant dog have been described for both the normal and abnormal foreleg [15]. The formation and fusion of the centers of ossification in the developing skeleton of the cat have been reported [19]. The normal radiographic appearance of the forelimb bones in the dog from birth to maturity has not been documented. The changes seen radiographically following premature closure of the distal ulnar physis are shortening of the ulna and curvature of the forelimb [2, 10, 15]. An overgrowth of the radius may also contribute to the lateral deviation of the paw [15]. Premature closure of the distal radial physis in dogs is seen less commonly than premature closure of the distal ulnar physis [10, 17]. Premature closure of the proximal radial and/or ulnar physis has not been reported in the dog. In man, injury of the distal radial and ulnar physes causes deformities similar to those seen in the dog [13, 16, 18]. In man the epiphyseal vessels nourish the stem cells of the distal physis of the long bones. If this network of vessels is damaged the growth potential of these physes is impaired. Interruption of the metaphyseal vascular system by fracture tends to result in a transient growth problem even when there is good reduction of the fracture. A longitudinal growth disturbance of the distal physis may result from this transient alteration in the rate of enchondral bone formation in the ulna or radius even if growth continues at a normal rate in the other physis of the same bone [14, 21, 22].

Another entity in the dog is a cartilaginous core with irregular margins which occurs in the distal metaphysis of the ulna. Histologic examination of this area in dogs shows increased numbers of unaligned hypertrophied cartilage cells. There is a diminished amount of vascular tissue invading these hypertrophied cartilage cells [6, 15].

In rabbits, metaphyseal ischemia results in an increased length of hypertrophic cartilage cells which extended deeply into the metaphysis with a total lack of calcification of the intercolumnar matrix [22, 23]. The radiographic and histologic similarity of hypertrophied cartilage cells in the dog compared with the rabbit would suggest a similar vascular ischemic cause in the dog.

### **Bone Circulation**

During bone growth the perichondrium is transformed into periosteum. Bone is completely covered on the outside by periosteum except at the sites of articulations; these areas are covered by hyaline cartilage. The inside of the medullary cavity is lined by the membranous endosteum which covers all the cancellous bone. This endosteum has but a single layer of cells whereas the periosteum is composed of an inner or cambium layer and an outer fibrous layer. Much of the blood supply to bone is provided by the endosteum and periosteum. In long bones the blood circulation is further enhanced by the presence of a nutrient artery which enters the bone along its diaphysis [22, 23].

This vessel gives off branches to the Haversian system and terminates in the medullary canal in the form of sinusoidal capillaries. Osteocytes receive their nourishment by way of the Haversian canals, the transverse channels (Volkmann's canals), and finally by diffusion through the canaliculi. Through the bathing of bone cells by blood and lymph there is a constant exchange of nutritional elements and waste matter comparable to the exchange taking place in any other cells of the body. The process of tearing down and building up goes on throughout life, but is particularly noticeable in bone that has been injured or subjected to undue stress [20, 22, 23].

In this study, the most important aspect of bone circulation to be analyzed is the nutrient artery of the ulna which gives off the metaphyseal vessels that terminate in many straight branches which penetrate the degenerating cartilage columns during the transformation of mineralized cartilage to bone. Interruption of the nutrient vessels has no effect on chondrogenesis in the physis. The physis increases in thickness since cartilage production continues, although transformation of cartilage into bone ceases. It is quite evident that bone is a complex substance and under certain circumstances behaves in a most amazing yet logical manner. The person who handles this substance with understanding will greatly improve his chance of success.

### **MATERIALS AND METHODS**

In this experiment the dogs that were used were medium size dogs of slow growth rate. The major portion of this study is concerned with attempts to determine the effects of ligating the palmar interosseous artery (which gives off the nutrient artery of the ulna) on the development of the distal ulnar metaphysis and physis. A sample of dogs was obtained from two populations: one from the Comparative Cardiovascular Studies Unit, University of Pennsylvania, School of Veterinary Medicine; one from a dog pound of the Veterinary Policlinic, University of Zululand, Faculty of Veterinary Sciences.

Both forelegs of all puppies were radiographed at weekly intervals between one month and five months of age.

#### **Group 1**

At two months of age two dogs with congenital heart disease but normal forelegs were euthanized and post-mortem arteriograms of the radius and ulna were made. Heparin was injected intravenously immediately prior to euthanasia with intravenous pentobarbital to prevent the formation of clots within the vessels.

For the post-mortem arteriograms the forelimbs were removed by cutting through the muscles connecting the limb to the trunk and neck. Immediately after death, contrast material\* was injected manually into the brachial artery through an

\* Microtrast (micro-opaque cream) 70% w/w Barium Sulphate mixed with Berlin Blue 2.5%. PICKER CORPORATION, MEDICAL PRODUCTS DIVISION, CLEVELAND, OHIO, U.S.A

angiographic catheter. The catheter was removed, the artery ligated, and survey radiographs were made.

Dissection and photography of the vessels were performed to correlate the gross anatomy with the radiographs.

## Group 2

In six normal one-month-old puppies ablation of the right ulnar nutrient artery was accomplished by surgical ligation of the palmar interosseous artery. The left foreleg was the control. Radiographs of both front legs were taken just prior to the ligation and at weekly intervals after ligation.

In two 8-week-old dogs and two 12-week-old dogs ligation of the left nutrient artery was performed and radiographs were taken weekly until 20 weeks of age (5 months). During this time interval arteriograms of both front legs were performed.

Physical examination including creatine levels and complete blood counts\*\* were performed in the normal puppies to exclude any sick dog from the project. All puppies in Groups 1 and 2 were fed with the same diet\*\*\* in the same manner. At the time of nutrient artery ablation bones were labelled by the administration of tetracycline *in vivo* [4, 5]. Tetracycline has the property of becoming bound in osteoblasts at the site of active growth. The tetracycline labelled cells can be detected because they fluoresce under ultraviolet light [8, 9]. Oxytetracycline hydrochloride\*\*\*\* was administered intravenously at a dose rate of 44 mg per kg. bodyweight.

The arteriographic technique used in Group 2 was the same as that described for Group 1. All bones were examined macroscopically and histologically, particularly at the distal aspects of the radius and ulna.

## Radiographic Examination

A 300 mA/126 kVp and a 200 mA 120 kVp x-ray machines were used for radiography. Craniocaudal and lateral radiographs of the forelimbs were taken using a standardized technique chart. Intensifying screens were used for the live animals. Kodak nonscreen high detail AA Industrial film was used for the post-mortem radiographic studies.

The radiographs were developed in a Kodak X-omat MGN 90 second developing system and in a manual technique. They were interpreted on a conventional view box.

## Significance

The radius and ulna each have two physes, each one growing at different rate. Normal development of the radius and ulna in the dog depends upon proportionate longitudinal growth. If injury or other stimuli delay or accelerate the

development of one of these four physes and cause disproportionate growth, bone deformity and malalignment of the limb will occur. An insufficient blood supply to the ulna has been hypothesized as a cause for at least one type of primary ulnar deformity seen in the dog [15, 22]. The blood supply to the distal ulnar metaphysis comes from the nutrient artery which enters the bone in the proximal metaphysis.

In this study it has documented the effects of ligating the palmar interosseous artery which gives off the nutrient artery of the ulna as a cause of a retained core of cartilaginous tissue at the level of the distal midportion of the ulnar metaphysis.

## RESULTS

**A.** Gross radiographic changes in the distal ulna after ablation of the nutrient artery by ligation of the palmar interosseous artery in six 4-weeks-old dogs.

The right forelimbs were used for the surgical procedure. The left forelimbs were the controls. The left ulnae and radii appeared radiographically and histologically normal during the entire experiment.

Surgery done at four weeks of age (observations made in six dogs) One week post-operatively (FIG. 1).

Radiographically the bone density of both radii and ulnae was normal except for the distal metaphysis of the right ulna. The right distal ulnar metaphysis was very irregular, greater in diameter than the control, and heterogeneous in density. The length of the ulnar diaphysis was 0.5 to 0.6cm shorter than the control.

The right radius did not have any abnormalities. The vascular supply from the nutrient artery of the radius was not compromised in any dog.

Two weeks post-operatively (observations made in six dogs) (FIG. 2).

The distal ulnar metaphysis was increased in diameter and the radiographic density of this area was variable. The ossification center of the distal epiphysis of the ulna became visible radiographically at this time (six weeks of age). There was a greater than normal distance between the epiphysis and the irregular metaphysis by approximately 0.4 – 0.5cm. There was a radiolucent concavity present in the distal ulnar metaphysis. Bone flaring around the metaphysis was observed. The ossification center of the distal epiphysis was smaller than the control and slightly irregular. There were no abnormalities noted in the right radius and carpal bones.

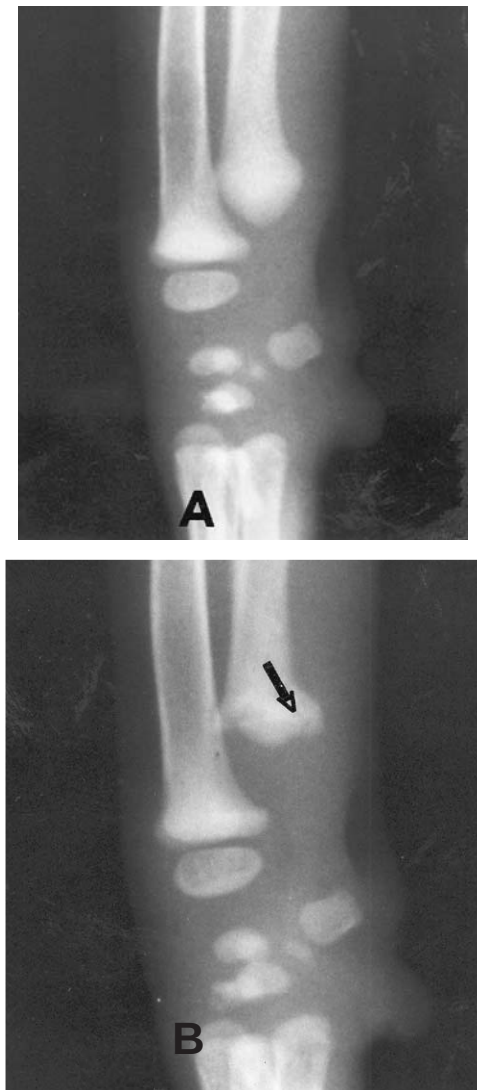
Three weeks post-operatively (observations made in six dogs) (FIG. 3).

\*\* Creatine levels were within normal limits in all dogs (0.8 to 1.2mgr%). Complete blood counts were within the normal range (W.B.C. 5,500 to 9,800 per mm<sup>3</sup>). R.B.C. 5 to 7.8 millions per mm<sup>3</sup>

\*\*\* Wayne Dog Food, Allied Mills, Inc., Chicago, Illinois, U.S.A.

\*\*\*\* Liquamycin, Department of Veterinary Medicine, Pfizer, Inc, New York, N.Y., U.S.A.





**FIGURE 1. SURGERY PERFORMED AT 1 MONTH OF AGE; ONE WEEK POST OPERATIVELY. A NORMAL (CONTROL) LEFT LEG. RIGHT LEG. HETEROGENEOUS DENSITY, INCREASED DIAMETER, AND IRREGULAR BORDERS OF THE DISTAL ULNAR METAPHYSIS ARE OBSERVED (ARROW). THE ULNAR DIAPHYSIS IS SHORTER THAN THE CONTROL.**

The distal ulnar metaphysis was greater in diameter than the control but not quite as irregular as at two weeks postoperatively. There was a wedge-shaped radiolucent area present in the distal metaphysis. The apex of the wedge extended proximally into the metaphysis approximately 0.5cm.

The radius was normal in size, shape, and density in both limbs. The proximal epiphyseal ossification center of the affected ulna was radiographically visible at this time but was irregular and smaller than in the control leg. There was increased metaphyseal diameter, and the length of the ulnar diaphysis was 0.2-0.3cm shorter than the control.

Four weeks post-operatively (observations made in six dogs)

The distal ulna metaphysis was increased in density and diameter. No irregularities were observed. The length of the diaphysis remained 0.2 to 0.3cm shorter than the control. The proximal epiphysis of the ulna was irregular in shape, smaller and decreased in density in comparison with the control. No abnormalities were observed in the right radius and carpal bones.

Five weeks post-operatively (observations made in six dogs)

The ulnar diaphysis remained shorter by approximately 0.2cm than the control. There was a minimal difference in density and size of the left and right distal ulnar metaphyses. No irregularities were noted. Both epiphyses were normal in size, shape, and density. Arteriograms of the control and affected legs were performed. No remarkable differences were observed between both limbs.

Six weeks post-operatively (observations made in six dogs)

Both radial and ulnae were radiographically similar in shape, size, and density. No abnormalities were observed in any of the areas where they were present previously. At 3 months of age (eight weeks post-operatively) all six dogs were radiographically normal in their forelimb. No deformity or lameness was observed.

**B.** Gross Radiographic changes in the distal ulnar metaphysis after ablation of the nutrient artery by ligation of the palmar interosseous artery in two 8-week-old dogs.

One week post-operatively (observations made in two dogs)

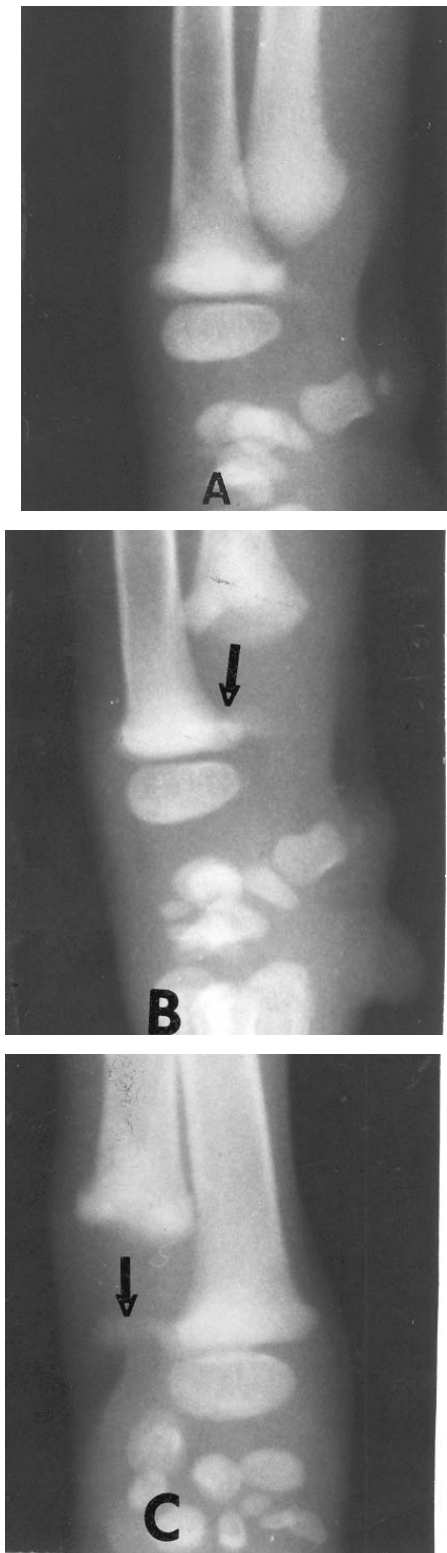
The distal physis of the affected ulna was approximately twice the diameter of the control. The distal metaphysis was very irregular and increased in diameter. The entire length of the ulnar diaphysis was 0.4 to 0.5cm shorter than the control. An increased density was observed in the distal metaphysis. The radius of the control and affected legs were similar in size, shape, and density.

Two weeks post operatively (observations made in two dogs) (FIG. 4).

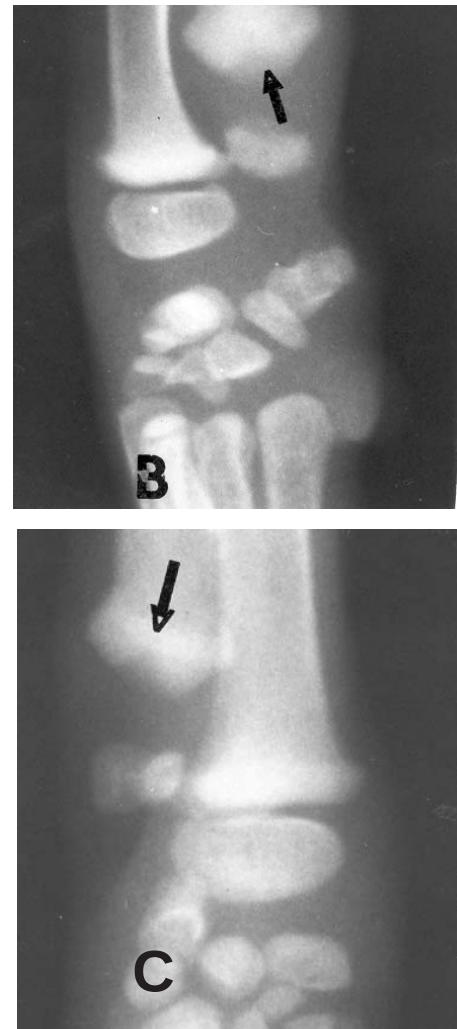
An increased in diameter of the distal ulnar physis was again observed, particularly more in the cranial half. The distal metaphyseal contour was very irregular and increased in density. The entire length of the ulnar diaphysis was 0.3 to 0.4cm shorter than the control. The distal epiphysis had a similar shape, size and density when compared with the control. At this time a wedge-shaped radiolucent area was observed in the distal diaphysis. It had the density of cartilage. The apex of the wedge-shaped radiolucent area extended proximally and deeply into the metaphysis.

Three weeks post operatively (observations made in two dogs) (FIG. 4).

The distal ulnar metaphysis was increased in density. The width of the most cranial aspect of the distal physis was



**FIGURE 2 SURGERY PERFORMED AT 1 MONTH OF AGE; TWO WEEKS POST OPERATIVELY. NORMAL LEFT LEG (CONTROL). B,C. RIGHT LEG. IRREGULAR METAPHYSEAL BORDERS, INCREASED DIAMETER AND A RADIOLUCENT CONCAVITY ARE PRESENT IN THE DISTAL ULNAR EPIPHYSIS IS PRESENT AT THIS AGE (ARROWS).**



**FIGURE 3. SURGERY PERFORMED AT 1 MONTH OF AGE; THREE WEEKS POST OPERATIVELY. B, C RIGHT LEG. A WEDGE-SHAPED RADIOLUCENT DEFECT IS OBSERVED IN THE DISTAL ULNAR METAPHYSIS (ARROWS).**

greater than the caudal aspect. A wedge-shaped radiolucent area was again observed in the distal ulnar metaphysis. At this time arteriograms of the forelimbs were made to correlate the radiographic findings with the angiographic findings. The nutrient artery of the right ulna filled well as did the normal vasculature of the entire control forelimb. In contrast, there were multiple, irregular, tortuous, and dilated vessels present throughout the entire length of the right ulna, particularly at the most caudal aspect of the limb where collateral circulation from the current ulnar artery was observed. Again, the nutrient artery of the right ulna was not visualized radiographically. At that time both dogs were euthanized and radiographs of the forelimb bones were made.

The left ulna had normal filling of the nutrient artery. Both radii were similar in vasculature, size, shape and density. The distal right ulnar metaphysis contained a wedge-shaped segment of cartilaginous tissue at the level of its cranial and mid



**FIGURE 4. SURGERY PERFORMED AT 2 MONTHS OF AGE. TWO WEEKS POST-OPERATIVELY. A. NORMAL (CONTROL) C. RIGHT LEG. INCREASED IRREGULAR DISTAL ULNAR METAPHYSIS IS NOTED. A WEDGE-SHAPED RADIOLUCENT AREA IS OBSERVED (ARROW). D. ARTERIOGRAM OF THE RIGHT LEG SHOWS INCREASED DILATED, IRREGULAR VESSELS IN THE DISTAL ULNA (ARROW).**

portion. The right ulnar metaphysis was irregular and greater in diameter than the control.

**C.** Gross radiographic changes in the distal ulnar metaphysis after ablation of the nutrient artery by ligation of the palmar interosseous artery in two 12-weeks-old dogs.

One week post-operatively (observations made in two dogs).

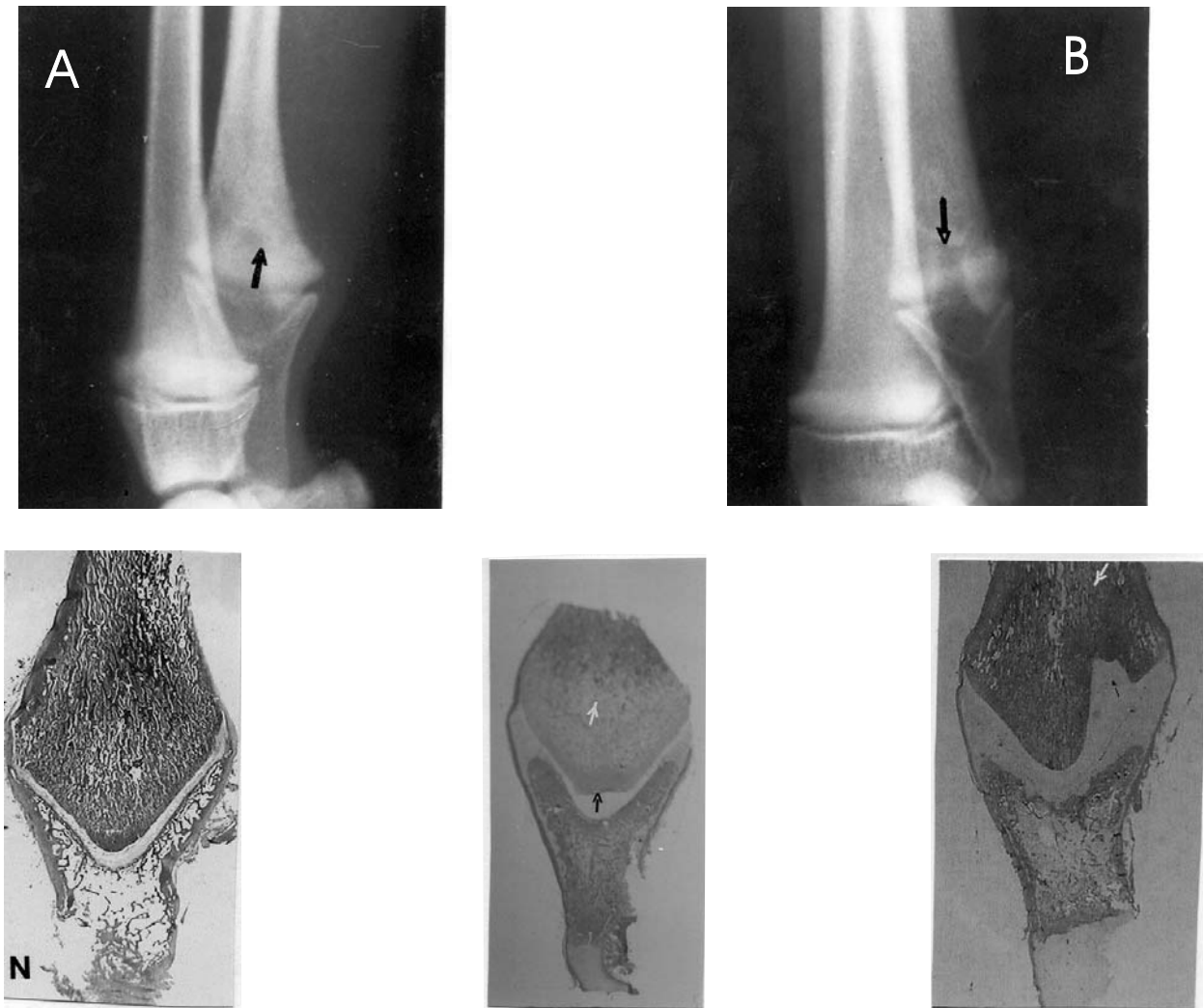
The left leg was selected for the surgical procedure, the right leg was the control. The left distal ulnar metaphysis was increased in density and diameter. The distal ulnar physis was 2-3 times as wide as the control one. The proximal epiphysis of the left ulna was decreased in density. The left radius was similar in size, shape, and density to the control. No abnormalities were observed in the distal epiphysis. The entire length of the left ulnar diaphysis was 0.5 to 0.6cm shorter than the control.

Two weeks post operatively (observations made in two dogs).

The left distal ulnar metaphysis was irregular in contour and increased in density and diameter. Slight flaring of the caudal border of the physis was observed. Increased width of the distal physis was present. There was a concave radiolucent area in the mid portion of the distal ulnar metaphysis. This concave radiolucent area extended proximally into the metaphysis about 0.8cm. The distal ulnar epiphysis was slightly irregular at its most distal aspect. The left ulnar diaphysis was 0.4 to 0.5cm shorter than the right one. The radius in both legs was normal.

Three weeks post operatively (observations made in two dogs) (FIG. 5).

The density of the distal ulnar metaphysis was decreased. There was a triangular wedge-shaped radiolucent defect present in the distal ulnar metaphysis similar to the one



**FIGURE 5. SURGERY PERFORMED AT THREE MONTHS OF AGE; THREE WEEKS POST-OPERATIVELY. A RADIOLUCENT WEDGE-SHAPED AREA IS NOTED IN BOTH VIEWS (LAT AND AP) EXTENDING PROXIMALLY IN THE ULNAR METAPHYSIS (ARROWS). HISTOLOGICAL SECTIONS SHOW A NORMAL ULNAR METAPHYSIS AND A DEFECT IN THE MOST DISTAL ASPECT WITH A WEDGE SHAPED AREA OF CARTILAGE TISSUE EXTENDING PROXIMALLY IN THE ULNAR METAPHYSIS. NOTE THE ISCHEMIC AREA (WHITE ARROW). HE X 40.**

observed in retained enchondral cartilage of the ulna in giant young dogs. This radiolucent defect extended deeply into the metaphyseal area about 1.2 to 1.4cm. The distal ulnar metaphysis was slightly irregular. Arteriograms made at that time showed that there was a poor blood supply to the distal metaphysis from the nutrient artery in the left ulna. There were multiple, irregular, dilated vessels present along the entire length of the ulna. No changes were noted in the epiphysis of either ulna or radius. The entire length of the ulnar diaphysis was 0.4 to 0.5cm shorter than the control.

Four weeks post-operatively (observations made in two dogs)

There was a decrease in density of the left distal ulnar metaphysis.

The radiolucent defect seen at three weeks was very well outlined and had a sclerotic border. At the apex of the radiolucent defect there was a transverse to semioblique opaque line suggesting a stress line fracture or scar tissue line. The entire length of the ulnar diaphysis was 0.3 to 0.4cm shorter than the control. No deformities were observed.

Six weeks post-operatively (observations made in two dogs)

Both ulnae were similar in length and shape. The distal metaphysis of the left ulna showed the same radiopaque line observed on week previously. The control ulna was normal. At that time both dogs were euthanized for histological examination and measurements of the bones.





**FIGURE 6. A. FRACTURES OF THE RADIUS AND ULNA ARE PRESENT AFTER AN AUTOMOBILE ACCIDENT IN A 2 ½ MONTHS OLD DOG. B. THREE WEEKS LATER (13 - 14 WEEKS OF AGE) A RETAINED CORE OF CARTILAGE IS OBSERVED IN THE DISTAL ULNAR METAPHYSIS DUE TO INTERFERENCE WITH THE BLOD SUPPLY OF THAT AREA (ARROW).**

Interruption of the metaphyseal vascular system by fracture tends to result in a transient growth problem even when there is good reduction of the fracture. Figure 6 shows a clinical case of a retained enchondral cartilage in a 3.5 month old dog three weeks after a traumatic injury.

**D.** Histological findings in the distal ulna. Figure 7 shows radiograph and photomicrographs of a retained enchondral cartilage in a 3.5 month old giant dog.

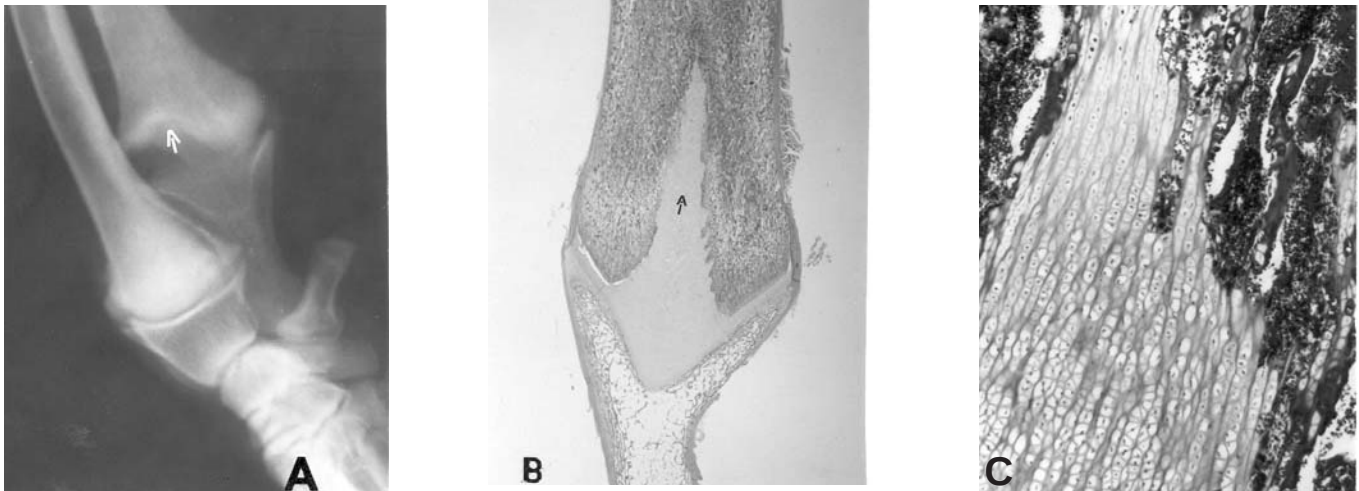
The majority of the bone specimens were submitted for histologic evaluation five weeks post-operatively. Two 2-month-old

dogs were euthanized at two and three weeks post-surgery and histological examination of the forelimb bones was done. In these two dogs ulnae there was increase in width of the distal physis. There was a retained core of cartilaginous tissue present in the distal metaphysis (FIG. 8). The columnar cartilage cells were increased in number and extended proximally in the metaphysis. The metaphyseal primary bone trabeculae were irregular in shape and variable in size. There was lack of blood vessels at the level of the distal portion of the metaphysis where the extension of columnar cartilage cells was present. The blood supply of both sides to the increased retained cartilaginous tissue and adjacent to the bone cortices was normal. There was disorganization in the arrangement and location of the primary trabeculae. An increased amount of the interlacunar matrix at the level of the distal metaphysis was present. The lack of blood vessels at the level of the distal mid portion of the metaphysis together with the extension of columnar cells and increased amount of interlacunar matrix, became more visible from the first to the fifth week post-operatively. Three weeks after surgery in three-month-old dogs there was an increased number of unaligned hypertrophied cartilage cells and a diminished amount of vascular tissue invading the cartilaginous tissue. There were also enlarged empty lacunae in the distal metaphysis representing empty blood vessels. All the histological changes observed in all the dogs in the distal ulnar metaphysis and physis after ablation of the nutrient artery of the ulna are similar to those changes present in young growing giant dogs in the distal ulnar metaphysis. The radiographic changes observed in the distal ulnar metaphysis and physis post-operatively were correlated with the histological findings in all the dogs.

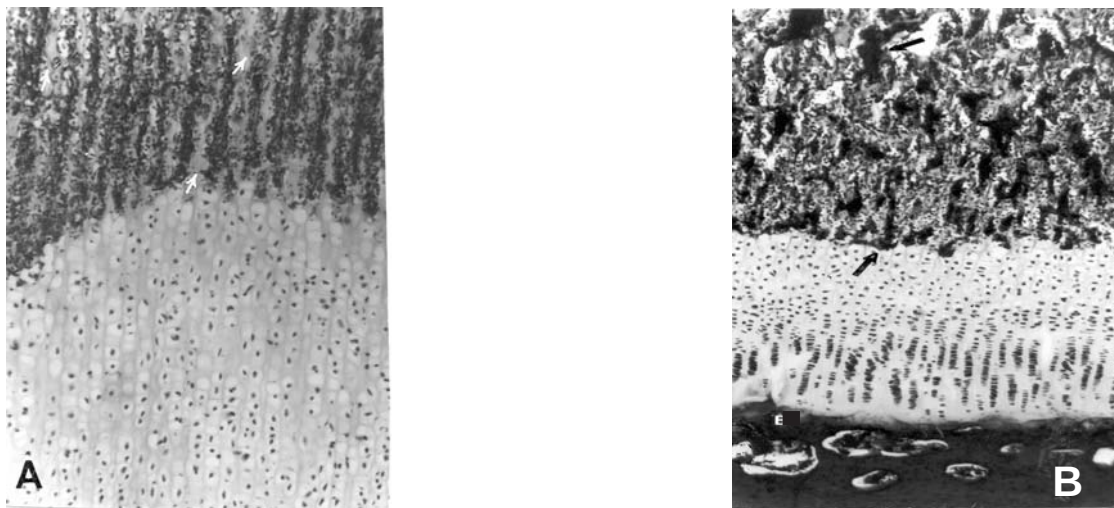
## DISCUSSION

The author considers that the retained core of cartilage cells observed in young giant dogs with a very rapid growth rate is responsible for deformities of the forelimb due to diminished blood supply to the distal ulnar metaphysis. The fastest growing period of giant breeds occurs at 3 to 5 months [12]. The blood supply to the distal midportion of the ulnar metaphysis which comes from the nutrient artery seems insufficient for the conversion of cartilage cells into bone. A cartilage core remains. A retained core of hypertrophied cartilage cells will persist until collateral circulation is established. During the period of decreased blood supply the ulna experiences a delay in longitudinal growth. Meanwhile the radius continues to grow longitudinally at a normal rate. This rate is faster than the ulna and a bowing deformity of the forelimb is observed.

The ulna is the longest bone of the dog. In giant dogs like great dane, mastiff, etc. its blood supply from the nutrient artery is one straight small artery which gives off very few and very short branches at the level of the distal metaphysis. The nutrient artery enters the ulna in the proximal metaphysis. In contrast, the adjacent radial nutrient artery enters the bone al-



**FIGURE 7. A, B. GROSS APPEARANCE OF A RELATIVE CORE OF CARTILAGE CELLS. IN A 3½ OLD GIANT DOG. C. PHOTOMICROGRAPH SHOWING THE CARTILAGE CELLS EXTENDING PROXIMALLY IN THE METAPHYSIS. HE X 800. THESE PHOTOGRAPHS ARE NOT FROM THE SAME DOG.**



**FIGURE 8 A. IRREGULAR ARRANGEMENT OF THE COLUMNAR CARTILAGE CELLS IS OBSERVED. TWO WEEKS POST-SURGERY IN A TWO MONTH OLD DOG. LACK OF BLOOD VESSELS IN THE AREA OF PRIMARY TRABECULAE IS NOTED (ARROWS). HE X 400. B. NORMAL LEFT ULNAR PHYSIS AND DISTAL METAPHYSIS, MULTIPLE VESSELS IN THE AREA OF PRIMARY TRABECULAE ARE SEEN IN THE NORMAL LEFT ULNA (CONTROL). HE X 200.**

most at the level of the mid diaphysis and gives off several tortuous branches which serve the distal metaphysis over a broad area. During growth the ulnar diaphysis is located more proximally than the radius in relationship to the carpus; its distal epiphysis has a styloid shape and appears radiographically between 14 to 28 days later than the radial epiphysis it has. To grow faster than the radius if longitudinal growth of these two bones is to be proportional. When some giant breed dogs experience their fastest longitudinal growth rate, the metaphyseal vessels of the ulna are not long enough in comparison with the radius to maintain proportional growth. Anatomically the ulna differs from the radius. The distal epiphysis is conical in shape, long, and grows much more actively than that of the distal radius. The proximal ulnar physis is relatively inactive and contributes very little to the ulnar length.

## CONCLUSIONS

The changes which occurred in the distal metaphysis and distal physis of the ulna following ablation of the nutrient artery by ligation of the palmar interosseous artery are considered to result from a diminished blood supply to the metaphyseal region. The areas which were more sensitive to the diminished blood supply were the zone of ossification of the distal physis. In these areas the matrix and cartilage cells did not undergo changes in preparation for their transformation into bone, and the osteoclastic activity in the resorption phase in the metaphysis did not occur until collateral circulation was established. The diminished blood supply to the zone of ossification of the distal ulnar physis resulted in interference with matrix elaboration and bone formation. The distal ulnar physis therefore was

wider than normal and the projection of hypertrophied cartilage cells into the mid portion of the metaphyseal area was present. The first changes observed radiographically were widening of the distal physis accompanied by an increased metaphyseal density and multiple irregularities along the most distal aspect of the metaphysis which were noted four days post-operatively. The irregularities in the distal metaphyseal region were less obvious at 15 to 20 days post-operatively. A wedge-shaped radiolucent defect with its apex extending deeply into the metaphyseal region was observed from 20 to 40 days (4-6 weeks) after surgery. This radiolucent area corresponds to that observed histologically where the diminished vascular tissue and increased number of columnar cartilage cells were present.

The increased metaphyseal density present from two days after surgery became less obvious at 5 to 6 weeks post-operatively when it resembled the normal leg. At seven weeks post-operatively the entire length and width of the ulna was similar to the normal control leg, apparently due to establishment of the collateral blood supply.

The increase in density of the metaphyseal region noted from 4 days to 35-40 days post-operatively resulted from a persistence of mineralized cartilage cells due to diminished blood supply to that area. As the collateral circulation was sufficient to invade the mineralized cartilage cells, normal appearing bone trabeculae developed and the radiographic appearance of the distal metaphysis became normal. The wedge-shaped radiolucent area observed at 3 to 5 weeks post-operatively in the distal ulnar metaphysis was similar to that observed in young growing giant dogs where forelimb deformities are considered to be a common problem. One of these deformities occurring in giant dogs is associated with a retained hypertrophied core of cartilage cells in the distal ulnar metaphysis. In this study it has demonstrated that by ablation of the ulnar nutrient artery a diminished blood supply to the distal ulnar metaphysis produces a similar retained core of cartilage cells. In this experiment with medium size dogs no leg deformities were observed.

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