Radial and Ulnar Osteotomy (1-Jan-1985)

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Radial, ulnar, or radial and ulnar osteotomy is a technique often needed to treat abnormalities of the canine forelimb. Osteotomy is necessary to correct malunions and forelimb deviations resulting from growth plate abnormalities. The following material is taken, with minor modifications, from Riser and Shirer (1965).

DEVELOPMENT FEATURES OF THE RADIUS AND ULNA

The radius and ulna, together with the carpus, develop as a unit, and normal growth depends upon a synchronization of the growth of these bones. The radius and ulna each have two growth plates, and each plate grows at a different rate.

RADIUS

The longitudinal growth of the radius follows the pattern of most long bones and expands by enchondral conversion of cartilage to new bone. On the radiograph, the epiphyses, growth plates, metaphyses, diaphysis and nutrient foramen are easily identified (Fig. 41-1).

At birth the epiphyses of the radius are composed of cartilage, and are not visible radiographically. By 12 to 14 days of age a mineralized epiphyseal nucleus (ossification center) appears radiographically; osteogenesis can also be seen histologically. Before four weeks of age, the entire outline of both epiphyses is visible on the radiograph.

The growth plates are composed of cartilage and appear radiographically as radiolucent lines. These are the areas where bone length is added. During active ossification, the cartilage cells proliferate, line up in columns, mature, hypertrophy, calcify, and disintegrate, leaving a straight strip or core of noncellular calcified cartilage matrix on which new bone is deposited by
the osteoblasts. These newly formed cores of bone are called primary trabeculae.

The newly mineralized primary trabeculae, which become the metaphysis and are situated adjacent to the growth plate, are very radiopaque. These primary trabeculae are replaced by secondary, and then tertiary trabeculae, finally the cortex of the diaphysis is formed. The bone at the growth plate is very wide; the shaft narrows at the cut-back zone as it tubulates into the diaphysis.

In the radius, under normal conditions 70% of the growth takes place at the distal metaphysis, while 30% occurs in the proximal area. The amount of growth at each end can be accurately determined from a radiograph by locating the nutrient foramen and then measuring the percentage of bone present on either side of this vessel. In the embryo, the nutrient vessel, when it penetrates the cartilage mold, marks the center of each long bone.

In a growing bone, an estimate of the degree of radiopacity present in the metaphysis at each growth plate and the size of the expanded metaphysis also serve as guides to the amount of growth activity that is taking place, e.g., the distal end of the radius during growth shows greater density, and the metaphysis is larger in diameter than the proximal metaphyseal area.

ULNA
Anatomically, the ulna is quite different from the radius. The distal epiphysis is long and pointed, and its growth plate is conical and grows more actively than that of the distal radius. At birth, the distal epiphysis is composed of cartilage. The epiphyseal nucleus ossifies and appears radiographically and histologically from two to three weeks after birth (which is later than the appearance of the radial epiphyses). The epiphyseal apex (the styloid tip) ossifies even later than does the proximal half. The proximal ulnar growth plate stretches across the tip of the olecranon, is relatively inactive, and contributes little to ulnar length.

The nutrient foramen of the ulna is located on its dorsal (cranial) surface, in close proximity to the dorsal ulnar articular surface of the elbow, adjacent to the proximal radial epiphysis. The proximal location of the nutrient vessel (embryonically located in the center of this bone) indicates that longitudinal growth from the proximal (olecranon) growth plate has been restricted to 15% of the total length, while the distal growth plate provided the remaining 85%. From this, it becomes evident that the distal ulna must grow at least 15% faster than the distal radial companion if the two bones are to remain equal in length.

Accelerated growth is accomplished by the development of anatomical features: (1) the conical shape of the distal growth plate, and (2) the increased diameter of the entire ulnar shaft. The conical shape of the ulnar plate increases the growth surface area by 1.5 times over a flat area of the same diameter.

The diameter of the ulna during growth in the giant breeds increases, apparently to accommodate the added enchondral bone production; it diminishes in diameter as growth slows. The ulna at four to five months of age commonly is as much as 50% larger in diameter than the radius; at seven to nine months, the two bones are about the same size. In adult life, when remodeling and resorption are complete, and the growth plates have closed and the metaphyseal bulging has disappeared, the ulnar diameter is one half that of the radius. Most of the excess bone is absorbed from the lateral side.

MANAGEMENT PROBLEMS CAUSED BY GROWTH PLATES
Many physeal plate problems can lead to deformity of the forelimb. The severity of the deviation and the technique used to correct the problem depend on the specific epiphyseal plate injury and the age of the animal when injured. When the cause of deformity is recognized in an immature animal, the plan of treatment will probably be prophylactic, that is, minimizing subsequent deformity as the animal grows to maturity. This may require multiple surgeries as the animal continues to grow. To wait for the animal to grow to maturity without any correction may allow for formation of deviation beyond correction and may allow subluxation or luxation of the elbow or carpus to develop. Successful reconstructive surgery at that point is impossible. Conversely, the older animal, close to growth plate closure or beyond, can be corrected completely when the problem is recognized and toward an end point.

The proper management of radial and ulnar physeal plate injuries is difficult and requires the clinical judgment of the surgeon. The 10-week-old pup with growth plate abnormalities must often be treated differently than the 5-month- or 8-month-old pup. Treatment depends upon the period of growth remaining.
The specific reasons for radial and ulnar osteotomy will be discussed as they apply to the following:

- Slowing of the distal ulnar physis in giant breed dogs
- Premature closure of the distal ulnar physis
- Slowing of the distal lateral radial physis
- Closure of the distal lateral radial physis
- Closure of the distal radial physis
- Closure of the proximal radial physis
- Malunion of the radius and ulna

DISTAL ULNAR PHYSEAL GROWTH DISTURBANCES IN DOGS

ETIOLOGY

Most distal ulnar growth plate problems originate as a result of trauma, hypertrophic osteodystrophy, or retained ulnar enchondral cartilage core. More recently an inherited distal ulnar closure has been recognized in Skye terriers.

Trauma, usually automobile or crush injuries, to the forelimb may result in premature closure. The trauma may be directly to the growth plate in the form of a severe bruise or may result in fracture. Such direct trauma is not always needed, however, to result in closure. Any trauma to the forelimb of an immature dog sufficient to cause radial and ulnar fracture may also result in growth plate closure. Owners of immature dogs with radial and ulnar fracture should be warned of the possibility of distal ulnar growth plate closure.

Hypertrophic osteodystrophy may result in growth plate closure. This disease produces proliferative bone outside the periosteum in the metaphyseal regions of developing bone. In extreme disease this proliferative bone can bridge the ulnar growth plate and result in its cessation of lengthening and physeal closure.

Retained enchondral cartilage in the ulnar metaphysis is the result of abnormal cartilage turnover in the distal ulnar physis. This is a common problem in giant breed dogs. The retained cartilage can be seen radiographically in the metaphyseal area of the ulna as a radiolucent strip, or core, which extends as much as 3 cm or 4 cm into the metaphysis. Grossly the tissue is clear, firm, and resilient. Microscopically, the core is composed of hypertrophied hyaline cartilage cells piled in long columns. There seems to be an absence of adequate vascular tissue to penetrate and destroy these cells. The cartilage on either side of the retained core ossifies normally. Retention of this cartilage core seems to retard the total overall growth in the length of the ulna (Fig. 41-2).

PATHOGENESIS OF DEFORMITY

Forelimb deformity begins with shortening in ulnar length due to retarded or discontinued growth at the distal ulnar physis. Initially the radius bows cranially, owing to the shortened ulna acting as a "bowstring." The bowing may result in a hyperextended carpus, and the proximal row of carpal bones may assume a position abnormally caudal to the distal end of the radius. Next the radius bows medially, forcing the limb to deviate laterally into valgus. In the valgus position, the carpal axis deviates from a position parallel to the elbow to one angled abaxially. With continued radial growth, the radius begins to rotate externally, around the short ulna, resulting in external rotation of the paw. External rotation may be slight (in a late distal ulnar physeal closure) or as much as 90° (in an early closure, i.e., growth disturbances at 2 to 3 months of age). Simultaneously, the shortened ulna begins to sublunate ventrally out of the elbow. In extreme cases, the ulna can luxate completely, resulting in total elbow instability.

FIG. 41-2 Seven-month-old Great Dane. Lateral (A) and cranial-caudal (B) radiographs show premature closure of the distal ulnar physis and a retained enchondral core (arrow). Valgus and anterior bowing are already evident. (Newton CD: Surgical management of distal ulnar physeal growth disturbances in dogs. J Am Vet Med Assoc 164:479, 1974)
PRESENTING SIGNS AND DIAGNOSIS
Dogs with distal ulnar physeal growth disturbances usually bear weight on the affected limb. Limb pain or lameness that is usually associated with the deformity has three basic causes: (1) ligamentous injury or osteoarthritis of the carpus, resulting from long-standing deviation; (2) elbow subluxation and associated osteoarthritis as the anconeal process pulls distally against the caudal surface of the medial humeral condyle; with total ventral subluxation of the proximal end of the ulna, the limb appears flaccid owing to the lack of stability at the elbow; (3) external rotation, forcing the dog to walk on a nonpadded surface, thus causing decubitus ulcers to form on the dorsal and medial sides of the paw.

Radiography will enable the clinician to confirm the diagnosis on the basis of a closed or narrow distal ulnar physis, deformity if present, or distal subluxation of the proximal end of the ulna. Radiography will also aid in eliminating animals with luxations or subluxations of the carpus from consideration as candidates for osteotomy.(9)

SURGICAL TREATMENT OF THE ULNA PRIOR TO CLOSURE OF THE DISTAL RADIAL PHYSEIS
Early treatment may preserve normal elbow articulation and minimize curvature of the radius. In the progression of the deformity, proximal ulnar distal subluxation causes most of the pain and lameness. The anconeal process impinges on the caudal surface of the humerus, causing osteoarthritic changes that often are visible radiographically. Total luxation causes gross joint instability. The primary purpose of early ulnar osteotomy is to prevent distal subluxation of the proximal ulna, but radial deformity may be decreased as well. Four procedures are available.

REPETITIVE ULNAR OSTEOTOMIES
Minimal elbow subluxation occurs if early ulnar osteotomy is performed. After osteotomy, the interosseous membrane is cut to free the proximal end of the ulna from the radial shaft. The proximal end of the ulna may occasionally snap back into its normal anatomical place, but if it does not, the osteotomy site must be spread and held open by a cortical bone graft. It may be necessary to repeat the procedure inasmuch as the proximal and distal radial physeal plates remain open the ulnar osteotomy site will unite readily. Continued growth of the radius after the osteotomy site unites may result in reformation of the radial deformity.

ULNAR OSTEOTOMY AND PROGRESSIVE SPREAD OF THE ULNA
Early ulnar osteotomy may prevent radial deviation if the growth of the ulna keeps up with that of the radius. To prevent union in young dogs, a half-pin or full-pin transfixation can be attached to a Stader spreading apparatuses Opening the apparatus progressively every fourth day delays union of the ulna, permitting the ulna to lengthen at approximately the same rate as the radius.

ULNAR OSTEOTOMY AND INDUCED CLOSURE OF THE PROXIMAL RADIAL PHYSEIS
If subluxation is a major problem, two procedures may be performed: ulnar osteotomy and relocation of the proximal end of the ulna into the elbow, followed by transfixation into the proximal end of the radius to maintain reduction. Either the transfixation device or a separate orthopaedic staple should be used to close the proximal radial physeis, reducing the probability of reluxation. Removal of a large segment of the ulna(11,20)or insertion of a mechanical block such as fat prevents union of the ulna.

ULNAR STYLOID TRANSPOSITION
Experimental results indicate that the distal ulnar physis may be resected entirely with a significant amount of the distal ulna. The remaining ulnar styloid process is reattached to the distal radial epiphysis by means of a screw. The experiments indicate that this procedure allows continued radial growth, prevents progression of deformities, and in certain instances allows spontaneous correction of existing deformities if sufficient radial growth potential remains.

FAT GRAFTS
Autogenous fat grafts have been used successfully to prevent bony union following ulnar osteotomy.
RESECTION OF THE ANCONEAL PROCESS
Resection of the anconeal process relieves pain, but subluxation continues. The resultant instability may produce a nonfunctional limb if resection is performed during early stages of the growth disturbances. This procedure is not recommended.

RESECTION OF THE RADIAL HEAD
Resection of the radial head has been proposed as a method for dealing with abnormalities of the proximal radius. In animals with premature closure of the distal ulnar physis, this procedure destroys the only relatively normal supporting structure within the elbow. Resection results in instability of the elbow and probable loss of limb use; it is not recommended.

SURGICAL TREATMENT OF RADIAL DEFORMITY PRIOR TO CLOSURE OF THE DISTAL RADIAL PHYSIS
Ulnar section is the most effective correction in the early stages of radial deformity. Although stapling the distal radial physis may correct or arrest the radial deviation, especially when dealing with retained enchondral cores in giant breed dogs, the procedure results in a shortened limb. Stapling is best reserved for correction of primary injury to the radial physis.

Osteotomy and correction of the radial deformity before closure of the distal radial physis is a half-way measure. The deformity will recur if the physis remains open and the limb will be shortened if fixation causes premature closure. Therefore, ulnar osteotomy is the most realistic approach while the radial physis remains open. Radial cuneiform osteotomy should be used after physeal closure.

TREATMENT OF RADIAL AND ULNAR DEFORMITY AFTER CLOSURE OF THE DISTAL RADIAL PHYSIS
After closure of the distal radial physis, all corrective procedures are done with the goal of returning the paw to a functional position. In the process, many cosmetic benefits may result as well. To obtain proper functional and cosmetic results, the paw must be rotated to a neutral position, valgus must be reduced to normal, and the cranial bow must be reduced to a more normal curve.

To provide the necessary corrections, oblique or cuneiform osteotomy may be performed. Oblique osteotomy in the region of the major radial deviation, with simultaneous oblique ulnar osteotomy, has two advantages: preplanned cuts are not required and, theoretically, limb length may be gained. A 45° oblique cut is made in the radius and ulna in the region of the maximal radial deviation. After osteotomy, the proximal radial fragment is reduced into the medullary canal of the distal fragment.

Using the medullary canal as a pivot, all three corrections are accomplished simultaneously. Fixation may be provided with halfpin splintage or bone plate. Inasmuch as only small surfaces are in contact for union, stability of fixation may be a problem.

A bone plate should be affixed to the anatomical cranial surface of the distal fragment to correct the deviation. Use of compression ensures solid fixation and rapid union of bone ends (Fig. 41-3).

FIG. 41-3 Twelve-month-old Afghan hound. Lateral (A) and cranial-caudal (B) radiographs of the forelimb show anterior bowing, valgus and lateral rotation. Lateral (C, D) radiographs following oblique osteotomy of the radius and ulna. Some limb length, as well as correction of the deformities, was gained. Lateral radiograph (E) of osteotomy sites 7 months postoperatively. (Newton CD: Surgical management of distal ulnar physeal growth disturbances in dogs. J Am Vet Med Assoc 164:479, 1974)

When half-pin splintage is used, the exposure may be closed as soon as the osteotomy site has been reduced. Placement of pins should be as far proximal and distal in the radius as possible to gain stability. Correction is accomplished by realigning the limb and tightening the external apparatus; if necessary, reduction can be altered prior to union. Half-pins may loosen or encourage pin tract infection if they are not cared for properly.
Cuneiform (wedge) osteotomy provides flat surfaces for bony union and therefore more stability. It is possible to estimate the correction of cranial bowing and valgus by means of preoperative radiography, but rotation cannot be measured on survey radiographs. Lines drawn through the physes parallel to the elbow and carpus in the craniocaudal view meet to provide the angle needed to correct valgus. Lines drawn axially through the radius on lateral radiographs meet to show the angle of the cranially based wedge to be removed (Fig. 41-4).

Transverse osteotomy of the radius is accomplished at the most proximal end of the radial deviation with simultaneous oblique division of the ulna. The distal radial fragment should be rotated back to neutral. Using the estimated angles, a biplane wedge is removed from the radius, with the base cranial and medial, tapering caudally and laterally. This wedge should correct valgus and cranial bowing. If insufficient, the correction may be supplemented by reversal of the wedge and its introduction into the caudal and lateral side of the osteotomy.

A bone plate and compression technique should be used for fixation. The plate should be kept straight and the osteotomy site reconstructed to the plate. Fixation of the distal end of the radius to the plate is accomplished by placing the plate on the anatomical cranial surface; the osteotomy site is then reduced in a corrected position. The plate is attached to the proximal end of the radius, using compression. Fixation is not used on the ulna because the oblique osteotomy provides point contact for union to occur. Inasmuch as the radial osteotomy surface is transverse and smooth, fixation with an intramedullary pin, staples, or a plaster cast could result in nonunion and should be avoided if plates are available.

Many times proximal ulnar subluxation will be encountered simultaneously and must be corrected. In addition to the cuneiform radial osteotomy, transverse proximal ulnar osteotomy must be performed. Dissection of the intraosseous ligament and muscle will allow for anatomical reduction of the semilunar notch of the ulna. The reduction is held by the interfragmentary screw fixation or multiple pins. When both problems occur, the ulnar osteotomy and repositioning should be performed first and will usually negate the need for more distal ulnar osteotomy when the radius is cut (Fig. 41-5).

**DISCUSSION**

Premature or retarded closure of the distal ulnar physis results in multiple deformities of the affected forelimb. The severity of the deformities depends on the age of onset of closure. The elbow, distal portion of the radius, and carpus will be involved if closure occurs at an early age. Late ulnar closure usually results in distal deviations, not osteoarthritis of the carpus and elbow.

Treatment requires either an early decision to make multiple, small corrections or one major correction after closure of the distal radial physis. Early correction consists of ulnar osteotomy to reconstruct the elbow and allow unrestricted growth of the radius; it prevents major deformities and gains a maximal amount of limb length. The expense and the time involved for multiple procedures are drawbacks. Late treatment, after closure of the distal radial physis, requires one major correction and possible elbow reconstruction; however, abnormal weight bearing for 3 to 5 months often results in irreparable osteoarthritis changes within the carpus and elbow. Stapling the distal radial physis is unsatisfactory, since limb length will be sacrificed.
Treatment depends on the estimate of changes to the joints. If an injury occurs at 6 to 8 months when little growth potential remains, one correction is preferable. If closure of the distal ulnar physis occurs between 3 and 5 months, early management is necessary to prevent major joint changes prior to closure of the distal radial physis.

Coaptation splints or plaster casts are not suitable for correction of the deformities. They invariably result in multiple decubital lesions and no marked changes in deviation. In addition, splinting has no effect on elbow luxation.

DISTAL LATERAL RADIAL PHYSEAL GROWTH DISTURBANCES
Premature closure of the distal lateral radial physis can result in severe developmental deformities of the involved forelimb. Recognition of the problem early in its course is necessary to minimize valgus deformity and secondary osteoarthritis of the elbow and carpus.

ETIOLOGY
Deviations in growth of the canine forelimb have been recognized for a number of years. The most common problem involves premature or incomplete closure of the distal ulnar physis. The resulting deformities have been well described, as have many methods of treatment. Deformities can also develop as a result of incomplete or premature closure of the distal radial physis. This problem has been recognized for as long as the ulnar closure problem but was believed to occur only rarely. At an orthopaedic referral center, at least 50% of the distal radial or ulnar epiphyseal plate problems in dogs were due to distal radial physeal closure. The primary cause was complete distal radial epiphyseal plate fracture (Salter type I). The initiating event was a fall from a height or automobile trauma.

PATHOGENESIS OF DEFORMITY
The progression of this growth disturbance can be followed radiographically. The first radiographic sign is usually the premature closing of the distal radial physis. The entire physis may close, but more often the lateral side closes first and is recognized as a narrowed lateral physis, gradually widening as it approaches the medial aspect of the radius. The next radiographic sign is distal subluxation of the radial head, with resultant increase in joint space at the radiohumeral articulation. The subluxation occurs because growth of the radius has slowed while the ulna has continued to grow. The medial and lateral collateral ligaments of the elbow attach the humerus with the radius; therefore, as the ulna continues to grow, the radius holds the humerus by means of the collateral ligaments, resulting in proximal subluxation of the ulna in relation to the humerus. As the condition progresses, the ulna may completely luxate proximally. The progressive lateral to medial closure of the distal radial physis may result in valgus deformity of the forepaw, and the radial carpal joint may luxate dorsally.

CLINICAL SIGNS
Dogs with distal lateral radial physeal closure are presented for various reasons, depending on the length of time the condition has been present. Usually they are first presented with forelimb lameness. Pain on passive manipulation of the elbow or valgus deformity may be evident. Later in the course of the disease, dogs have pain from ligamentous injury or...
osteoarthritis of the elbow due to prolonged radial head and proximal ulnar subluxation. Radiography will confirm the physeal closure, radial derotation, and radial head subluxation.

SURGICAL TREATMENT PRIOR TO CLOSURE OF THE DISTAL ULNAR OR RADIAL PHYSES
Early surgical treatment has three goals: maintenance of a normal elbow; prevention of deformity; and preservation of limb length. To accomplish these goals, the problem must be recognized early. This can be done only by complete history, thorough physical examination, and radiography.

Treatment must be vigorous and dynamic. Perfect relocation of the humerus in the semilunar notch of the ulna will be only temporary unless postoperative adjustments can be made while the distal ulnar physis continues to increase the length of the forearm.

Midshaft radial osteotomy and progressive radial spread is accomplished using a Stader apparatus or other spreading device applied to the craniolateral surface of the limb to open the osteotomy site progressively.

At surgery, two pins are placed in the proximal radial diaphysis and two in the distal radial diaphysis. The midshaft of the radius is exposed and a transverse osteotomy is performed. Inasmuch as the ulna is left intact, relatively little instability results after the spreading apparatus has been applied. Correct pin placement can correct valgus deformity (Fig. 41-8).

The osteotomy site is spread by the external spreading apparatus every 4 days to lengthen the radius and prevent rapid union. The spreading apparatus is opened until the radial head is firmly pushed up against the humeral condyles. This procedure can usually be done with the dog awake, with or without an analgesic. The limb is then radiographed for positioning and length. This adjusting process usually is continued for about 5 weeks or until the radius heals. The external-spreading device is then removed and the limb is placed in a Robert Jones dressing for an additional week. Gain in limb length will be variable, depending on the dog's age, but 2 cm of length is not unreasonable in a 5-week period. By progressively forcing the radius to elongate, the valgus deformity can usually be averted. Should such a deformity begin to occur, the spreading apparatus can be progressively turned to compensate. Stapling the medial side of the radial physis may partially correct the valgus; however, one must be aware that it does not improve the elbow subluxation and is at best a partial correction.

SURGICAL TREATMENT AFTER CLOSURE OF THE DISTAL ULNAR PHYSES AND RADIAL PHYSIS
RADIAL AND ULNAR OSTEOTOMY
Radial and ulnar osteotomy can be carried out after the physes have closed. The procedure will correct a deformity of the distal portion of the limb but will not correct an elbow subluxation. The osteotomy site can be transverse, oblique, or cuneiform. Usually a cuneiform osteotomy is more appropriate. The desired wedge correction is estimated by analysis of radiographs. The desired end result is a parallel carpus and elbow joint.

The wedge is removed from the region of the greatest deformity, that is, from the medial surface or the craniomedial surface (if rotation has occurred) of the radius. The ulna should be sectioned obliquely to allow radial displacement. Plate fixation is best. It should be applied to the cranial surface of the radius.(12)
RADIAL OSTEOTOMY AND SPREAD, PLUS BONE GRAFTING
In radial deformity with elbow subluxation, two corrections must be made simultaneously. The radius is subjected to osteotomy to correct the valgus deformity, and the osteotomy site is spread to replace the radial head. Usually a spreading instrument is necessary to force the radial head back into its anatomical position; if the correction is difficult, the interosseous membrane may have to be sectioned. Following repositioning of the radial head, a cortical bone graft is inserted. The entire osteotomy area must be stabilized with a bone plate(2)

It is difficult to achieve accurate anatomical positioning of the limb when one is attempting to balance the corrective osteotomy on a graft while maintaining a spread and laying a plate over the entire area. The Richards plating system allows the plate to be placed under compression and the bone under tension to spread the osteotomy site.

RADIAL OSTEOTOMY AND PROGRESSIVE SPREAD
Radial osteotomy and progressive spread allows correction of the deformity and gradual repositioning of the subluxated elbow. Spreading during a period of many weeks permits the interosseous membrane to stretch slowly and allows careful control of the reconstruction of the elbow. The procedure is accomplished with an external spreading apparatus. 13 As described above, the amount of valgus deformity is determined radiographically. At surgery, pins are placed in the proximal and distal ends of the radius, each set being perpendicular to the long axis of the radial fragment. The radius is then sectioned transversely in the region of the greatest deformity. After straightening the limb and affixing the pins in the spreading apparatus, the lateral opening wedge osteotomy is stabilized. The procedure corrects the valgus deformity.

The spreading apparatus is opened every 4 days to reposition the radial head properly onto the humeral capitellum. By this procedure, union is prevented until the desired correction has been achieved (Fig. 41-9).

DISCUSSION
Management of radial physeal injuries is not easy. It entails constant monitoring and many small corrections if a normal limb is to result.

The best management involves early detection. Distal radial physeal closure, like its counterpart (distal ulnar physeal closure) must be anticipated when an immature dog injures or fractures its radius and ulna. Relatively minor trauma to these bones may result in partial or complete radial closure. Proximal radial physeal closure may complicate the situation by accentuating the radial shortening.

Once the lesion has been recognized, progressive radiography must be used to ascertain whether deformity is occurring; whether the elbow is subluxating; or whether the limb is shortening. Both the normal and abnormal limbs must be examined.

When deformity or radial head subluxation begins, the best treatment is immediate radial osteotomy and progressive spread. This procedure will allow the ulna to grow unrestricted and help alleviate deformities. This forced elongation of the radius will prevent radial head subluxation and resultant instability. If deformity continues, the spreading apparatus can be progressively corrected to neutralize the deformity.

If a dog has chronic deformities associated with distal radial physeal closure and has elbow abnormalities, the treatment is only slightly different. Such a dog should have radial osteotomy and correction followed by slow reduction of the radial head into the elbow, using the spreading apparatus.

The above procedures require meticulous care of the skin and soft tissues around the pins to prevent pin infection. The limb
and apparatus must be bandaged to prevent contamination of the pinhole area. Bandages should be changed every 4 days when the apparatus is lengthened.

If these two procedures are used correctly, there will be little likelihood that shortening, deformity, osteoarthritis, or pain will occur in a limb in which the radial physis closed prematurely.

When a mature dog has a deformity due to distal radial physeal closure but a normal elbow, standard radial and ulnar osteotomy will correct the deformity.

DISTAL RADIAL PHYSEAL GROWTH DISTURBANCES
ETIOLOGY AND PATHOGENESIS OF DEFORMITY
Trauma or disease (hypertrophic osteodystrophy affecting only the radius) may result in total closure of the distal radial physis. This is an uncommon problem.

In this instance, the ulna continues to grow initially while growth of the radius slows. Eventually the ulna bows laterally at middiaphysis, with the short radius serving as a "bowstring". The resultant bowing forces the limb distal to the carpus to deviate toward the midline, resulting in a varus deformity. Further ulnar growth may force the limb to rotate inward.

If the distal radial closure occurs in the very young animal, radial head subluxation will also occur.(16)

SURGICAL TREATMENT PRIOR TO CLOSURE OF THE DISTAL ULNAR PHYYSIS
Surgical management will mimic that described above for distal lateral radial physeal closure. The radius must be cut so that the ulna can grow without the restriction of its shortness. In many instances, spreading with the Stader device is ideal.

SURGICAL TREATMENT AFTER CLOSURE OF THE DISTAL RADIAL AND DISTAL ULNAR PHYYSIS
Surgery is identical to that described above for distal lateral radial closure. The deformity, however, is in varus; therefore, the cuneiform osteotomy will be laterally based and result in a valgus correction. Should radial head subluxation be a part of the problem, it must be corrected at the same time.

PROXIMAL RADIAL PHYSEAL CLOSURE
ETIOLOGY, PATHOGENESIS, AND DIAGNOSIS
Proximal radial physeal closure is a very rare problem(15) resulting from trauma. Clinically, the dogs present with progressive lameness, which is exacerbated by direct manipulation of the elbow. Deformity of the forelimb is unlikely.

Radiographs will demonstrate an increased space between the radial head and the distal lateral humeral condyle. Lateral displacement of the radial head, lateral curvature of the proximal radius, and oblique angulation of the radial joint surface may also be seen. It is difficult to know if this injury results in only radial head subluxation (ventral) or manifests itself as a lateral radial head subluxation as well. Both seem to result from the same type of injury.

SURGICAL CORRECTION
Correction necessitates proximal radial osteotomy. In instances of ventral subluxation, transverse osteotomy, spreading, and cortical bone grafting are indicated. When lateral displacement or angulation of the radial head is also occurring, the radial head fragment must be angled properly for articulation prior to internal fixation.

The problem warrants correction when diagnosed, since the instability in the elbow will lead to disabling degenerative joint disease.

RADIAL AND ULNAR OSTEOTOMY FOR FRACTURE MALUNION OR CONGENITAL DEFORMITY
Malunion of the radius and ulna usually results from premature removal of an internal Steinmann pin, premature removal of
an external cast or splint, or failure to recognize a fracture. In any case, as the animal bears weight, the limb distal to the unrecognized fracture site or incompletely healed fracture will deviate laterally into valgus. Most times the valgus is only minor and at most represents a cosmetic defect. Occasionally the valgus will be severe and result in significant lameness due to abnormal weight bearing on the carpus. Continued walking could result in subluxation, degenerative joint disease, or both.

When surgical correction is deemed necessary because of lameness, the osteotomy performed is identical to that described for endstage distal ulnar physeal closure. Congenital deformity may be corrected in the same manner.(18)

Using a cranial-caudal radiograph of the deformity, the surgeon draws a line parallel to the elbow and carpal physeal surfaces. This line will determine the angle of wedge to be removed. The cuneiform osteotomy should be performed at the site of the malunion. Internal fixation, Kirschner-Ehmer apparatuses, or long-leg casts may be adequate fixation if used properly. As in all other instances, fixation should not be removed until there is radiographic evidence of union.

COMPLICATIONS
Osteotomy is always an elective procedure and as such should be performed after adequate preparation by the surgeon and only on a healthy animal. Without these two conditions, surgery may be prolonged and result in infection, soft tissue destruction, inadequate correction, or fixation failures.

CONCLUSIONS
Radial and ulnar osteotomy is a useful reconstructive procedure to correct deformity of the forelimb. While the surgeon can physically correct the deformity by careful surgery, it is rare that the limb becomes totally normal. It must be remembered that the correction has helped immensely, but often periods of lameness may occur as a result of mild degenerative arthritis, which invariably accompanies these procedures. The results are always gratifying for the surgeon, owner, and animal, but perfection is rarely attainable.

REFERENCES

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