THE EFFECTS OF FIXATION OF THE ULNA

TO THE RADIUS IN YOUNG FOALS

by

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LITERATURE REVEIW

The equine elbow joint is a composite articulation of the distal humerus with the proximal radius and ulna. The olecranon tuberosity represents the proximal extent of the ulna and is usually defined as that portion of the ulna projecting proximal to the proximal radial physis or articular surface.[1] Although the radius and ulna both contribute to the articular surface of the elbow, the two bones have specific and different functions. The ulna serves as a non-weightbearing member of the antebrachium while providing a focus for the attachment of the triceps brachii and the for the transmission of extensor forces through the distal limb.[1] The radius functions as the axial load bearing member. As a two bone system in the horse, the radius and ulna are seperate during the early years of life, but develop in synchrony and fuse with time.[2] The exact time of fusion is unclear from the literature, but is believed to be variable between the ages of 3 and 7 years.

A variety of physes or growth plates contribute to longitudinal bone growth in the area of the elbow. The effects of alterations in the growth of indivdual physes may have devastating clinical effects upon the affected individual. The canine patient serves as a common example of the morbidity associated with physeal growth arrest.[3] Canine patients are susceptible to elbow subluxation as a component of the radius curvus syndrome resulting from early closure of the distal ulnar physis. An analogous situation in the horse would theoretically involve premature fixation of the ulna to the radial metaphysis, at a time when the proximal radius is still growing.

The proximal physis of the ulna functions as a traction epiphysis (apophysis) and as such, probably contributes minimally to the longitudinal growth of the olecranon. The specific contribution to ulnar growth and the development of the elbow joint by the ulnar apophysis is unclear, however retardation of the proximal ulnar physis in young growing foals failed to alter the development of the elbow and did not result in the development radioulnar subluxation.[4] The radius undergoes significant growth from its two physeal plates and contributes over 20% of the total increase in height from birth through 2 years of age.[5] The proximal radial physis contributes approximately 40% of the total elongation of the radius; a process which occurs rapidly during the first months of life and acheives 53% of its total growth by 3 months of age.[5] After this early rapid growth, the rate of radial growth begins to decrease, but continues until 14 to 18 months of age.[5,6]

Fractures of the proximal ulna or olecranon of the horse have been frequently reported and reviewed in the veterinary literature.[1,7-10] These fractures have been described as occurring with relatively frequency when compared to other equine fractures.[7] The highest incidence of ulnar fractures has been consistently observed in young horses, with 17 of 29 cases occurring in animals less than 3 years of age in one study[1],20 of 25 in another[8], and 34 of 43 in horses less than 2 years of age in a third.[9] Further evaluation by age at fracture incidence indicates that roughly 43% of the fractures occurred in horses less than 9 months of age, during the time of rapid skeletal growth.[1,8,9]

The clinical signs of ulnar fractures have been frequently described and are generally similiar from case to case.[7,8,11-13] The predominant clinical sign is that of a "dropped elbow" appearance with variable weight bearing on the affected limb. This characteristic clinical appearance is the result of a functional loss of extensor support from the triceps musculature to the lower limb following disruption of the biomechanical continuity of the ulna. Without triceps function, the animal is unable to fix the lower limb in extension by the normal means of the stay apparatus and is therefore dramatically limited in its ability to bear weight.[1]

A variety of approaches have been utilized for the management of ulnar fractures in the horse. These include both non-surgical and surgical modes of therapy. Non-surgical management of ulnar fractures has included stall rest and full-limb splintage with support of the contralateral limb. Despite the observation that selected ulnar fractures have been treated successfully with conservative therapy, the results of this type of management have been generally ineffective in returning the animal to athletic soundness.[9] Complications associated with non-surgical management have included flexural deformities of the affected limb, support limb laminitis, muscle atrophy, and degenerative joint disease of the affected elbow joint.[7] It has been recommended that non-surgical management be reserved exclusively for non-displaced, non-articular fractures in cases where economics are of primary concern.[7,9]

The surgical repair of ulnar fractures has become the accepted mode of therapy and has included the use of intramedullary pins, tension band wires, orthopedic screws, and bone plates.[10-14] The use of bone plates, applied along the tension surface of the ulna has become accepted as the surgical treatment of choice and has been extensively described in the literature.[1,7-9,11,12,14-17] Surgical fixation is indicated in most cases because of either the articular nature of the fracture or the extreme debility associated with the loss of the triceps axis. Failure to repair articular fractures without anatomic reconstruction of the affected articular surfaces will result in the development of degenerative joint disease.[1,7-9] Surgical reduction and fixation of the displaced ulnar fragment allows for immediate return of extensor function at the elbow and permits the animal to bear weight on the injured limb. This immediate return to weight bearing on the affected limb reduces the likelihood of fracture associated diseases such as laminitis or angular deformity of the support limb or flexural deformity of the affected limb. For these reasons surgical repair is recommended in all cases where return to soundness is desired.

The surgical approach and techniques for plate application have been described previously.[18,19] In young animals, the rudimentary distal ulna provides little bone for the anchorage of orthopedic appliances. It has been recommended that orthopedic screws placed to secure plates along the distal ulna also engage the radius for additional security and increased holding power.[7,19] Following the successful reduction and stabilization of the fracture fragments, the animal is generally weight bearing within 1 to 2 days. Generally, fracture healing progresses in an uncomplicated fashion, particularly in young patients which are of an age marked by a period of rapid skeletal growth. Postoperative complications which have been reported in association surgical repair have included soft tissue swelling, surgical wound dehiscence, infection, implant cycling and failure.[8] An additional complication which has been infrequently reported in young horses undergoing radioulnar fixation as a component of ulnar or radial fracture repair has been a progressive subluxation of the elbow joint.[8,19,20] While generally thought to be an uncommon occurence, it has been suggested in singular case reports that radioulnar fixation be avoided in skeletally immature patients.[7,21]

Similiar to fractures of the ulna, fractures of the equine radius are also prevalent in the pediatric patient.[22] In the repair of these fractures, the use of two bone plates has been advocated. Typically, one plate is placed on the tension surface of the radius and the other located at a 90 degree angle to the first. In cases where cortical defects exist in the caudal cortex of the radius, the defect must be bridged with the second implant.[23] To lend stability to such repairs, placement of the plate on the caudolateral aspect of the bone and incorporation of the ulna has been advocated.[19,21] Even without intentional incorporation of the ulna in attempted repair of radial fractures, it may be inadvertently transfixed by screws placed through other plates.[20] As with radial engagement by appliances utilized in ulnar fracture repair, elbow subluxation may also develop following radioulnar fixation associated with the repair of a fractured radius in a young patient.[20] In either case, the development of radioulnar fixation appears to be associated with serious clinical consequences.

Bridging between the ulna and radial metaphysis normally occurs in the adult.[2] Premature union of these two bones, prior to the cessation of proximal radial physeal growth, would fuse the ulna to the radius while the proximal radial physis was still undergoing elongation. Such an event could conceivably result in elbow subluxation as the proximal radius continued to grow. This process would occur as a result of radial pressure forcing the distal humerus to displace proximally and anteriorly on the olecranon. During internal fixation of olecranon and selected radius fractures, the ulna may be fixed to the radius to improve the stability of the repair. While such fixation is desirable from the standpoint of implant stability and ultimate fixation strength, it may present serious consequences when performed in the pediatric patient prior to the cessation of rapid proximal radial growth. The development of elbow subluxation following radioulnar fixation in young patients has been reported, but not evaluated in a controlled fashion.[8,20]

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SUMMARY

Twenty-one Quarter Horse foals were randomly assigned to four groups to study the effects of radioulnar fixation in the equine pediatric patient. Surgical fixation by application of a bone plate with screws placed to engage both the radius and ulna was performed at 1 month (6 foals), 5 months (6), and 7 months (3) of age. Six foals at 1 month of age served as sham operated controls. Sequential radiographic and clinical evaluations revealed the development of ulnar dysplasia and elbow subluxation in all non-control foals. The magnitude of dysplasia was inversely proportional to age at fixation and was accompanied by degenerative joint disease and lameness in foals undergoing fixation at 1 and 5 months of age. Removal of the fixation appliances in three foals from each of the 1 and 5 month of age groups failed to reverse ulnar dysplasia. Although foals undergoing fixation at 7 months of age did not exhibit clinical lameness, they did develop degenerative changes in the articular cartilage of the elbow of the operated limbs. Recommendations for avoidance of radioulnar fixation are made and alternative methods of fracture repair are advocated.

INTRODUCTION

Equine olecranon fractures and their repair by variuos methods have been frequently reviewed in the veterinary literature.[1-5] It has been noted that fractures of the olecranon are more common in the young equine patient; with approximately 43% of the reviewed cases occurring in horses under 9 months of age.[2-4] A recent review of equine radial fractures revealed that although these fractures occur in horses of all ages, successful surgical repairs appear to be common only among pediatric patients.[6] It is therefore apparent that candidates for surgical repair of either radial or ulnar fractures are often skeletally immature, pediatric patients.

The development of open reduction and internal fixation techniques has permitted surgeons to successfully manage a variety of potentially devastating equine orthopedic injuries.[7] Olecranon fractures have been repaired by a variety of internal fixation techniques including intramedullary pins and tension band wires, orthopedic screws, and bone plates.[5,7-10] The use of bone plates, applied in tension band fashion, has become accepted as the classical treatment of choice for the management of olecranon fractures and has been extensively described in the literature.[1-4,7-9,11-14] Internal fixation is necessitated in many olecranon fractures due to the articular nature of the fracture and the extreme debility associated with loss of triceps function. Nonsurgical management of olecranon fractures has generally proven to be ineffective and is not recommended if athletic performance is desired.[4] The repair of radial fractures has also been described and most frequently involves internal fixation by the application of two bone plates[7,16,17]. In the repair of either fracture it is possible and at times desirable to place the fixation appliance in such a manner as to engage and mechanically unite the ulna to the radius.[1,15,16] Radioulnar fixation permits the placement of orthopedic screws into considerably more cortical bone in order to develop greater implant security. It has been recommended that when these techniques are applied in skeletally immature individuals, that fixation appliances should be removed as early as possible.[1,7,15,16]

When planning a fracture repair in the pediatric patient, one must consider the effects which internal fixation appliances may have upon adjacent articulations and growth plates. When repairing antebrachial fractures, preservation of coordinated radioulnar growth is important to maintaining the integrity of the elbow joint. The canine patient offers an example of the morbidity associated with physeal growth arrest, asynchronous growth of the radius and ulna, and subsequent elbow subluxation.[18] Longitudinal growth of the equine radius accounts for over 20% of the total increase in the horse's height from birth to two years of age.[19] The proximal physis of the radius contributes approximately 40% of the total elongation of the radius; a process which occurs rapidly during the first months of life and achieves 53% of its growth by 3 months of age.[19] The proximal physis of the ulna contributes to longitudinal growth of the olecranon, but seems to have little impact on the elbow, as it can be bridged without deterimental effects.[7,20]

Concerns have existed regarding the effect of radioulnar fixation in pediatric equine patients.[1,7,15] There are several reports which detail the development of ulnar dysplasia and humeroulnar subluxation in foals following radioulnar fixation during the repair of an ulnar or radial fracture.[3,15,16] In these cases, a mismatch of proximal radial to ulnar growth appears to have occured as a result of mechanical fixation of the ulna to the proximal radial metaphysis. The opportunity for such asynchronous growth to occur secondary to radioulnar fixation is presumably present until approximately 18 months of age, at which time cessation of growth at the proximal physis has occurred.[19] Clinical complications associated with radioulnar fixation in the foal have not been well characterized.[16]

The objectives of our study were: 1) to characterize the response of the elbow joint to radioulnar fixation at various ages in the growing foal, 2) to determine the age range in which such fixation should be avoided, and 3) to determine if removal of fixation appliances would allow for resolution of elbow subluxation resulting from radioulnar fixation.

MATERIALS AND METHODS

ANIMALS AND EXPERIMENTAL DESIGN

Twenty-one Quarter Horse foals (11 male, 10 female) were randomly assigned at birth to one of four treatment groups. Six foals were scheduled to undergo surgical fixation of the ulna to the radius, as described below, at one month of age (Group I). Six foals were scheduled to undergo similiar fixation at five months of age (GroupII) Three foals scheduled to undergo surgical fixation at seven months of age (Group III). The remaining six foals served as sham operated controls (Group IV). All foals were housed with their dams in pens until weaning at 5 months of age. A standardized protocol of feeding, deworming and vaccination was applied to all animals.

Twelve hours prior to general anesthesia for surgical manipulation foals were not allowed access to solid feedstuffs. Procaine penicillin was administered intramuscularly (10,000 units/ lb) eighteen hours preoperatively and continued every 12 hours thereafter for 3 days post-operatively. General anesthesia was induced by intravenous administration of ketamine HCl (2.2 mg/kg) five minutes after premedication with xylazine (1.1 mg/kg) IV and diazepam (0.02 mg/kg) IV. Following anesthetic induction, an endotracheal tube was placed and anesthesia was maintained with halothane vaporized in oxygen and delivered through a semi-closed circle system. The foals were positioned in right lateral recumbency and the left forelimb was prepared and draped for aseptic surgery. The left forelimb was utilized for surgical manipulation in all foals to provide uniformity in the approach. A standard approach to the caudolateral surface of the ulna was utilized.[21]

Surgical fixation of the ulna to the radius was accomplished by application of a six hole narrow dynamic compression bone plate (DCP) to the caudal aspect of the ulna. The distal three cortical screws were placed in lag fashion through the plate and ulna to engage both cortices of the proximal radial metaphysis (Figure 1). The three bone screws were placed in the proximal olecranon at the level of the elbow joint. With the exception of screw application in lag fashion, the plate was applied utilizing standard ASIF techniques.[15]

The foals in Group IV (controls) were equally divided into two different sham operated subgroups. Three foals were sham operated by making an approach to the caudolateral surface of the ulna followed by routine closure without plate application. The remaining three foals were treated by plate application as previously described. The plate was then removed prior to incisional closure. Growth markers, intended for subsequent radiographic evaluation, were placed in the lateral distal humeral epicondyle, lateral proximal radial epiphysis, proximal radial metaphysis, proximal ulnar metaphysis and the ulnar apophysis. These consisted of metallic pellets placed into holes drilled into the cortical bone. Access to these sites was gained either through the operative site or seperate stab incisions. Closure of the surgical site in all cases was routine and included the application of a stent bandage for wound support and protection. Following recovery from general anesthesia the foal was returned to the stall. A single dose of flunixin meglumine (1.0 mg/kg IM) was administered as an antiinflammatory analgesic. Sutures were removed 14 days post-operatively.

TECHNIQUES OF EVALUATION

Anterior to posterior and medial to lateral radiographic veiws were obtained in all cases with the foals under general anesthesia or immediately following euthanasia. Radiographic examinations were made of the left elbow pre-operatively, immediately post-operatively, and at 2, 4, 8, 12, and 16 weeks postoperatively. Similiar views of the right elbow were obtained prior to surgery and at 16 weeks postoperatively for the purposes of comparison. Radiographs were examined for the presence of abnormalities in the area of the elbow. When present, any incongruity between the articular surface of the radius and that of the ulna was quantified by measuring the distance between the articular surface of the radius and the previously articular distal limit of the trochlear notch of the ulna. This measurement was then divided by the measured width or heighth of the adjacent proximal radial epiphysis (Appendix Figure 1). The resultant figure when multiplied by 100 provided the percent of growth disparity between the radius and ulna. Such a measurement and calculation negated the effects of radiographic magnification, paralax, and variable obliquity. The previously implanted metallic growth markers proved to be unreliable and were not utilized.

Foals were examined clinically at two week intervals for evidence of lameness or muscle atrophy. When noted, any lameness was graded on a scale of 1 to 5, with 1 being barely perceptible or visible only at the trot and 5 being non-weight bearing. Any evidence of muscular atrophy was characterized as mild, moderate or severe in comparison to the opposite limb. The standing angles of the joints of the forelimb were made and compared between left and right.

A complete postmortem evaluation was performed 16 weeks post-operatively in all but 6 foals (3 foals from Group I and 3 from Group II). The articular surfaces of the humerus, radius and ulna were examined grossly for evidence of cartilage erosion. Photographs were taken of the articular surface of the distal humerus, proximal radius, and proximal ulna. When present, gross cartilage changes were graded on a scale of 1 to 4, with 1 being normal and 4 representing severe ulceration with exposure of subchondral bone. Grades 2 and 3 represented increasing severity of cartilage fibrillation and/or loss.

Samples of the articular surfaces were obtained for histologic evaluation. These were decalcified, sectioned and stained with hematoxylin and eosin in routine fashion. Histologic evaluation of the joint surfaces was utilized to verify cartilage changes observed grossly.

Three foals from Group I and three from Group II were not necropsied at the end of the initial 16 week postoperative period. These six foals underwent a second surgery to remove the plate and screws from the left ulna. Following the removal of the fixation appliance these foals were monitored by radiographic and clinical examination as previously described for an additional 16 weeks postoperatively. At the end of this extended observation period, the foals were euthanized and a necropsy examination was performed according to the previously described protocol.

Statistical analysis was performed using the Stastical Analysis System (SAS) one-way analysis of variance procedure. The least significant difference (LSD) multiple comparisons technique was applied when more than two groups were compared. A p-value less than or equal to 0.05 was set as the level significance.

RESULTS

RADIOGRAPHIC FINDINGS

Signs of disparity between radial and ulnar growth, with the development of elbow subluxation, were noted radiographically in all experimental foals. In contrast, sham operated controls exhibited no abnormalities. Radiographic signs of elbow subluxation included distal displacement of the trochlear notch and coronoid processes of the ulna. This displacement resulted in the development of an incongrueity between the articular surfaces of the radius and ulna. This growth disparity was accompanied by radiographic evidence of shortening of the olecranon in experimental foals when compared to controls. Accompanying the articular surface disparity was a gradual flattening of the trochlear notch and anconeal process. These radiographic changes varied with the animal's age at fixation of the ulna to the radius and time following fixation as described below.

Experimental foals in Group I (surgical fixation of the ulna to the radius at 1 month of age) first exhibited radiographic signs of elbow subluxation 4 weeks post-operatively (Figure 2). The degree of subluxation increased at each evaluation period and at all times was significantly ($p < 0.05$) greater than that observed in foals in other groups (Figure 3). With removal of the fixation appliance 16 weeks after application, signs of subluxation failed to resolve and, in fact, continued to increase

(Figure 4). In addition to the previously described signs of elbow subluxation, these foals developed radiographic evidence of degenerative joint disease during the post-fixation evaluation period as evidenced by epiphyseal lipping and osteophyte formation along the articular margins. The anconeal process was observed to develop a fragmented appearance as subluxation progressed with time. The average degree of subluxation in Group I foals was 61.5% after 16 weeks of fixation and 82.0% following removal of the fixation appliance.

Foals in Group II (fixation at 5 months of age) first exhibited radiographic evidence of elbow subluxation at 8 weeks post-operatively. The degree of subluxation was increased at each evaluation period, but did not increase at a rate consistent with that observed in Group I foals (Figure 5). Similiarly, progressive subluxation continued to develop following removal of the fixation appliance. As in Group I, radiographic evidence of degenerative joint disease was observed. The average degree of subluxation was 37% after 16 weeks of fixation and 52% 16 weeks following removal of the fixation appliance.

Group III foals (fixation at 7 months of age) also developed radiographic evidence of elbow subluxation at 8 weeks post-operatively. However the subluxation in this group was significantly ($p < 0.05$) less than that seen in either Groups I or II (Figure 6). Evidence of degenerative joint disease secondary to subluxation was not observed during the evaluation period in

Group III foals. Removal of the fixation appliance was not performed in this group and therefore no comments can be made with regard to articular changes following fixation removal in this group.

The rate at which subluxation developed or increased is demonstrated graphically in Appendix Figure 2.

CLINICAL OBSERVATIONS

Foals in Group I developed a lameness in the operated limb which was evident 8 weeks following fixation. The lameness was characterized by a shortening of the anterior stride and a reluctance to bear full weight on the limb when at rest. On a scale of 5, the degree of lameness was graded as 2 to 3. In 2 of the six foals, a type I fexural deformity developed in the operated limb. The severity of the lameness, once evident, did not increase over the duration of the study. Foals undergoing evaluation after fixation removal were not more lame than those euthanized at 16 weeks after fixation. At the time of necropsy, all foals in this group had mild to moderate atrophy of the muscles overlying the shoulder. Synovial effusion was palpable in the craniolateral synovial pouch of the elbow joint of all Group I foals. Synovial fluid analyses were consistent with mild inflammatory disease of the joint.

Group II foals were lame to a lesser degree than that observed in Group I (grade 1 to 2). Clinical lameness was accompanied by mild atrophy in only 2 of the six foals. Lameness did not become clinically apparent until 10 weeks post-fixation. None of the foals in Group III exhibited either lameness or atrophy during the duration of the evaluation period

POST-MORTEM FINDINGS

On necropsy examination, the articular surfaces of the distal humerus, proximal radius and trochlear notch were examined for gross evidence of cartilage damage and the observations were scored by two seperate observers. All experimental foals had evidence of cartilage damage in the intercondylar groove of the distal humerus and trochlear notch of the ulna. The severity of gross cartilage damage was noted to vary with treatment groups. In more severely affected joints, the lateral plateau of the proximal radius was also involved.

Histologically, articular surface defects varied between groups, but were relatively consistent within groups. The most severe changes consisted of cartilage ulceration with exposure and sclerosis of the subchondral bone. Clusters of chondrocytes were observed adjacent to the cartilage defects. With chronicity, these deep cartilage defects could be seen to partially resurface with an ingrowth of fibrous tissue, either from exposed subchondral bone or the articular margin (pannus). Less severely affected joints exhibited cartilage erosion, fibrillation, and compression. These lesions were again accompanied by sclerosis of the subchondral bone and chondrocyte clustering. The severity of the changes varied inversely with the individuals age at the time of radioulnar fixation as described below.

Foals in Group I demonstrated marked cartilage erosion in the intercondylar groove of the distal humerus and trochlear notch 16 weeks after fixation (Figure 7). These lesions exposed the subchondral bone and were scored as 4 on a scale of 1 to 4. The articular surface of the proximal radius did not appear to be abnormal. A deficit was seen where the normal junction of the articular surfaces of the radius and ulna had been (Figure 8). This confirmed the radiographic impression that the trochlear notch had displaced distal to the level of the radial articular surface. Sixteen weeks following the removal of the fixation appliance, the articular surface defects in Group I foals had progressed to include the proximal radial articular surface, as evidenced by gross fibrillation and fracture lines on the lateral plateau. The lesions on the humerus and ulna continued to be scored as 4 in severity. The olecranon and particularly the anconeal process was shortened and flattened. Measurements of the distance from the proximal olecranon to the distal radial articular surface demonstrated a significant difference ($p < 0.05$) between the length of the operated and unoperated (control) limbs in each individual in Group I. This difference most pronounced in the subgroup undergoing extended evaluation following removal of the fixation appliance (Figure 9). Histologic examination confirmed the degree of involvement of the subchondral bone, with sclerosis and remodeling (Figure 10).

Group II foals had less severe cartilage lesions following 16 weeks of fixation. These were scored as 2 on a scale of 4 and were characterized by the presence of cartilage erosion without exposure of the subchondral bone (Figure 11). Histologically the cartilage wear extended into the radiate layer of the articular surface and there was sclerosis of the subchondral bone. Sixteen weeks following implant removal, the articular lesions had progressed to a score of 3 and histologically demonstrated evidence of some resurfacing by fibrous tissue originating from the margins of the articular surface (Figure 12). Shortening of the olecranon was noted when specimens were compared to the unoperated limb (Figure 13). Histologically, these lesions extended to the intermediate zone of the articular cartilage.

Sixteen weeks after fixation in Group III foals the articular surfaces exhibited mild cartilage damage. This was grossly scored as a 2 and histologically extended to the intermediate zone of the articular cartilage; some sclerosis of the subchondral bone was also evident (Figure 14).

Figure 1

Radiograph made in the immediate postoperative period of a Group I foal demonstrating the typical appearance of the implant.

Figure 2

Typical radiographic appearance of a Group I foal elbow 4 weeks following radioulnar fixation. Notice the distal location of the lateral coronoid process and limit of the trochlear notch of the ulna.

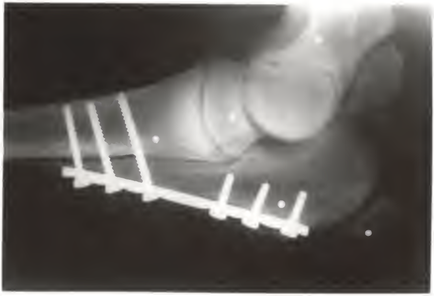


Figure 3

Flattening and filling of the trochlear notch and anconeal dysplasia were consistently observed in Group I foals 16 weeks following radioulnar fixation as demonstrated here.

Figure 4

Typical radiographic appearance observed in Group I foals 16 weeks following removal of the fixation appliance. Comparison to the radiographic appearance prior to implant removal reveals no significant reduction in the amount of ulnar dysplasia.

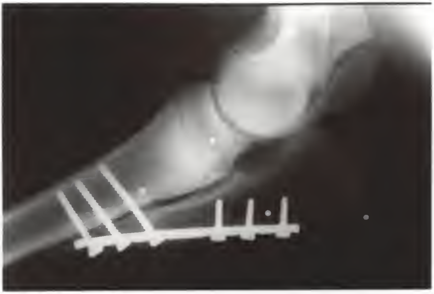
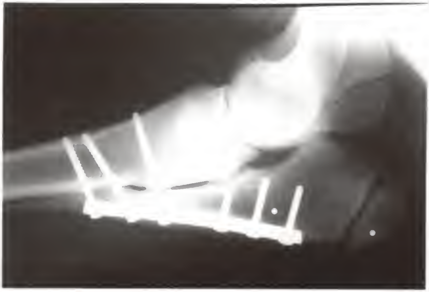


Figure 5

Radiographic appearance of Group II foal 16 weeks following radioulnar fixation. As with the Group I foals, flattening and filling of the trochlear notch, flattening of the anconeal process and shortening of the olecranon are noticed.

Figure 6

Radiographic appearance of a Group III foal 16 weeks following radioulnar fixation. A minimal amount of anconeal dysplasia is evident.



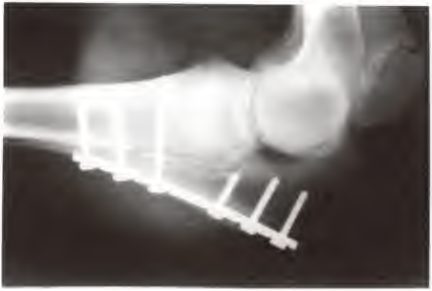


Figure 7

Marked cartilage loss with exposure and eburnation of the subchondral bone in the intercondylar groove of the distal humerus was observed in Group I foals during post-mortem examination, 16 weeks following radioulnar fixation.

Figure 8

Composite photograph demonstrating the articular changes observed at the junction of the olecranon and proximal radius of the operated (bottom) and control (top) limbs of a Group I foal. Notice the severe remodeling of the anconeal process and the associated chondromalacia.


#6 R


#6 L

Figure 9

Comparison of the operated (right) to the control radius and ulna typical in a Group I foal. Notice the shortening of the olecranon and flattening of the anconeal process.

Figure 10

Cartilage loss and exposed, sclerotic subchondral bone typically observed in Group I foals (Hematoxylin and Eosin, 60 x).

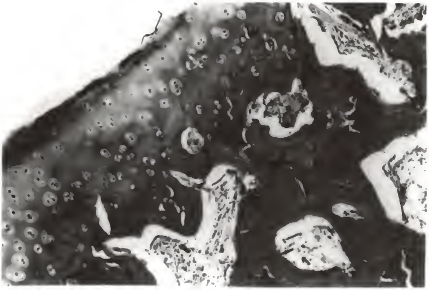


Figure 11

Cartilage fibrillation evident on the distal humerus of a Group II foal 16 weeks after radioulnar fixation.

Figure 12

Partial thickness cartilage erosion representative of the typical lesions observed in the elbow joint of the operated limbs of Group II and III foals. Notice clustering of chondrocytes and sclerosis of the subchondral bone (Hematoxylin and Eosin, 60 x).

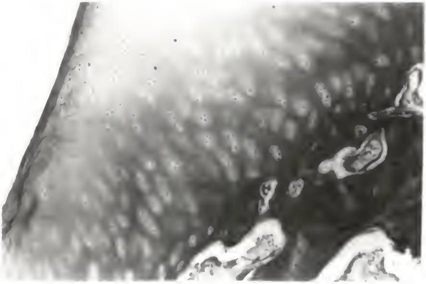


Figure 13

Comparison of the operated (right) to control radius and ulna in a Group II foal. Notice that the anconeal dysplasia is not as severe as that observed with the Group I foals.

Figure 14

Comparison of the operated (right) to control limbs of a Group III foal. Mild cartilage fibrillation was observed on the distal humerus.

DISCUSSION

The radiographic signs of elbow dysplasia or subluxation seen in this study were similiar to those reported in clinical cases of radioulnar fixation in foals.[3,16] Following fixation of the ulna to the proximal radial metaphysis, continued longitudinal growth at the proximal radial physis produces a mismatch of radial to ulnar growth leading to malarticulation. The ulna, in its fixed position, is unable to keep pace with proximal radial growth. The distal humerus is forced proximally, by the radius, against the anconeal process. Continued dysplasia, without remodeling of the articular surface of the olecranon would produce cranial as well as proximal subluxation of the distal humerus.

The articular surface of the olecranon was observed to remodel with filling of the trochlear notch and flattening of the anconeal process. Such remodeling is presumably the result of alterations in the forces placed upon the articular surfaces. In those pediatric patients in which the process of endochondral ossification has not been completed, the largely cartilaginous composition of the articular structures are susceptible to the occurence of plastic deformation and remodeling. Similiarly, this ability to deform could account for the flattening observed in the anconeal process. At the limit of plastic deformation, cartilage destruction and involvement of the subchondral bone will occur. Both of these changes were seen in the foals undergoing fixation at 1 and 5 months of age.

Quantitative analysis of the sequential radiographic evaluations made in each foal permitted measurement of the degree of articular dysplasia. Measurements made from radiographs are subject to variability due to patient positioning, magnification, and rotation. Consequently, we utilized the ratio of two measurements in an effort to standardize our evaluation of dysplasia. In that each measurement should vary equally in response to variations in positioning or magnification, the resultant ratio provides an absolute value for graphic and statistical comparison to control animals.

The magnitude of the articular dysplasia resulting from radioulnar fixation was inversely proportional to the foal's age at the time of fixation. Such a relationship, with the greatest degree of dysplasia occurring in younger animals, had been anticipated based upon the growth rate of the proximal radial physis.[16] Longitudinal bone growth in this region occurs most rapidly during the first few months of life and subsequently declines to cessation at the time of physeal closure.[22] Specifically, the proximal radial physis achieves over 50% of its total longitudinal growth by the age of 3 months.[19,23] The remainder of the growth at this physis occurs at a decreasing rate until approximately 18 months of age.[19] This reduction in growth rate after the first months of life accounts for the reductions in the amount of dysplasia seen in foals undergoing fixation at 5 and 7 months of age and probably explains why this condition is not observed in clinical cases which are operated beyond the age of 1 year or more. From this study, the amount of dysplasia observed in those foals undergoing fixation at 7 months of age would also tend to support the observation that fixation at older ages would probably develop minimal dysplasia. The continued growth of the proximal radial physis until the time of physeal closure, at approximately 18 months of age, would suggest that elbow dysplasia could still develop to some degree, albiet a clinically insignificant degree.

Similiar to the magnitude of subluxation observed in the foals of our study, the severity of gross and microscopic articular defects were also inversely related to age at radioulnar fixation. It was obvious that there was a strong correlation between radiographic subluxation and pathologic evidence of degenerative articular lesions. The gross and microscopic evidence of synovitis and cartilage loss observed in those foals undergoing fixation at 1 month of age suggests a poor prognosis for atheletic soundness. Conversely, foals undergoing fixation at 7 months of age failed to exhibit lameness and at necropsy had minimal damage to the articular cartilage; suggesting a better prognosis for future soundness. Certainly, in the event of continued subluxation, these foals could have progressed to more severe articular changes during a longer evaluation period. The decreasing rate of growth at the proximal radial physis and the fact that over 50% of its total growth was complete suggest that there was a reduced possibility of significant degeneration.

Other authors have recommended early removal of fixation appliances in cases of radioulnar fixation.[7,15] The results of our study demonstrate that implant removal 4 months after fixation fails to allow for resolution of acquired elbow subluxation. Continued or persistent subluxation probably results from the formation of an osseous union between the radius and ulna. It is conceivable that the development of a radioulnar synostosis was hastened by application of screws in lag fashion. However, the development of a synostosis has been reported in at least one case involving a fracture of the radius repaired with radioulnar fixation, but without lag application of screws thru the ulna and into the radius.[16]

Removal of fixation appliances earlier than 4 months post-operatively may precede the formation of an osseous radioulnar union and allow for some resolution of subluxation by continued growth. With the primary consequence of premature implant removal beingrefracture, one must exercise caution before proceding implant removal. Clinical and radiographic evidence of fracture healing should be demonstrable and in some cases supplemental stabilization may be necessary. The severity of articular changes noted in the Group I foals from this experiment suggests that the development of degenerative joint disease would be probable or likely, even if it were possible to correct the subluxation at that time.

Based upon our findings, we recommend that orthopedic techniques which produce radioulnar fixation be avoided in foals under 7 months of age. Additionally, it is our opinionthat such techniques should be utilized with caution and avoided whenever possible until such time as the growth at the proximal radial physis has ceased. When such techniques are employed in young growing foals, one can anticipate the development of ulnar subluxation and concurrent damage to the articular surfaces of the elbow. The magnitude of the articular response will be of the greatest clinical significance in foals undergoing fixation at an early (1 to 5 months) age. In cases in which radioulnar fixation by an orthopedic implant has occurred, the removal of the implant can not be relied upon to allow resolution of any resultant subluxation. Indeed, such fixation may lead to early development of a radioulnar synostosis which will maintain a mismatch of ulnar to radial growth even in the absence of an implant.

Alternative methods to the repair of olecranon fractures have been described and include intramedullary pins, tension band wires, and interfragmentary compression screws in addition to bone plating.[1-5,8-14] Each of these techniques has limitations; often imposed by the size and demeanor of the equine patient. It has been accepted that correct application of a compression bone plate to the tension surface of a fractured ulna is the most reliable means of achieving stable anatomic reconstruction and healing. This technique can be adequately performed in the pediatric equine patient without resulting in radioulnar fixation. Although the distal ulna in the foal is relatively narrow and lacks depth, careful screw placement can allow for stable fixation in a majority of the cases. In cases involving fractures of the radius with loss of the caudal cortex, a second plate placed on the caudal lateral aspect of the bone and engaging the ulna is often necessary for adequate fixation. In such cases it would appear that the development of radioulnar fixation in a pediatric patient would be unavoidable. Further study is required before a solution to this problem is found.

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APPENDIX FIGURES

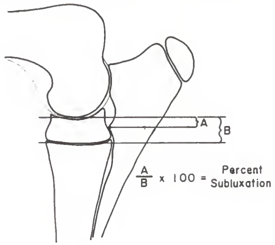
Figure 1

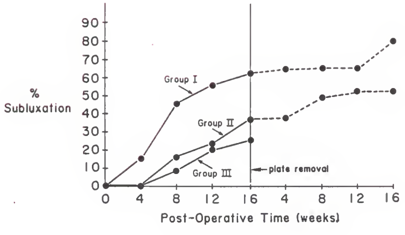
Schematic representation of the method used in obtaining measurements for calculation of the percent subluxation.

Figure 2

Graphic representation of the mean percent subluxation determined at each radiographic evaluation period in each group.

Objective Evaluation of Elbow Subluxation





THE EFFECTS OF FIXATION OF THE ULNA

TO THE RADIUS IN YOUNG FOALS

by

MICHAEL F. CLEM

B.S., New Mexico State University, 1979
D.V.M., Washington State University, 1983

AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

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ABSTRACT

Surgical repair of selected fractures of the ulna or radius in equine patients often includes the utilization of orthopedic implants which mechanically unite the ulna to the radius. In the equine pediatric patient, clinical experience has suggested that mechanical fixation of the ulna to the radius may occassionally result in elbow subluxation. The objectives of our study were a)to define the effects of radioulnar fixation at various ages in growing foals and b)to determine if ulnar dysplasia induced by fixation was reversible with removal of the fixation appliance.

Fifteen foals were divided into 3 groups for surgical fixation of the ulna to the radius at 1 month (6 foals, Group I), 5 months (6, Group II) and 7 months (3, Group III) of age. An additional 6 foals were sham-operated as controls (Group IV). Fixation was accomplished utilizing a 6-hole bone plate applied to the caudal aspect of the ulna with 3 screws placed through the ulna to engage the radial metaphysis. The fixation appliance was removed after 16 weeks in six foals; three from the 1 month and three from the 5 month of age at fixation groups. These foals were monitored for an additional 16 weeks.

Monitoring consisted of sequential clinical and radiographic evaluations performed biweekly for 16 weeks postoperatively. Necropsy examination was performed following the evaluation period in all foals.

All experimental (non-control) foals developed radiographic evidence of elbow subluxation. Radiographic changes included flattening and filling of the trochlear notch, flattening of the anconeal process, and periarticular osteophyte formation. The magnitude of subluxation was inversely related to age at fixation. Specifically, foals in Group I developed significantly ($p<0.05$) more ulnar dysplasia than those in Group II, which were significantly more affected than those in Group III. In both the 1 and 5 month of age groups there were grossly evident degenerative articular changes and lameness. The 7 month of age group developed superficial lesions of the articular cartilage, but failed to exhibit lameness. Subluxation did not resolve during the observation period following implant removal and necropsy revealed progressive articular degeneration. Sham operated control foals developed neither radiographic nor pathologic changes.

The results of the study suggested that radioulnar fixation should be avoided in foals under 7 months of age and that removal of fixation appliances should not be relied upon to resolve elbow subluxation and the accompanying clinical and pathological signs.