COMPARISON OF TWO SURGICAL PROCEDURES FOR THE ARTHRODESIS OF THE PROXIMAL INTERPHALANGEAL JOINT IN HORSES

by

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INTRODUCTION

Ankylosis of the proximal interphalangeal joint has been proven effective in the relief of pain and lameness associated with osteoarthritis of the joint. While ankylosis can be accomplished naturally, surgical arthrodesis will shorten the time necessary for fusion to occur and thus minimize extra articular exostosis. Five techniques have been described - 1) Placement of cross screws, 2) Placement of longitudinal screws, 3) Placement of foot in cast, 4) Dorsal plating, 5) Electrical current therapy, all in combination with destruction of the articular cartilage. Arthrodesis is becoming a common surgical procedure among veterinary surgeons and a successful therapy for osteoarthritis of the proximal interphalangeal joint. The question then arises which of the internal fixation techniques is most desirous and produces the strongest fusion with minimal exostosis. The investigation is designed to compare placement of cross or cruciate screws with the placement of three parallel longitudinal screws as a means of arthrodesis in the pastern joint.

REVIEW OF LITERATURE

Osteoarthritis of the proximal interphalangeal joint reduces the athletic ability of horses due to severe pain and lameness. According to Adams; "This condition is seldom found in thoroughbreds but is relatively common in other breeds."[1] Affected horses are usually in the prime time of their productive life thus the condition can significantly reduce their monetary value.

"The pastern joint synonymical with proximal interphalangeal articulation is a ginglymus formed by the junction of the distal end of the first phalanx and the proximal end of the second phalanx. The coffin joint synonymical with the distal interphalangeal articulation is a ginglymus formed by the junction of the second and third phalanges and the distal sesamoid bone."[2]

The articular cartilage is a typical example of hyaline cartilage, and lacks blood vessels, nerves, and lymphoid tissue.[3] On the surface the small chondrocytes are flattened and run parallel with the articular surface. The chondrocytes become larger and more round as the layers go deeper but are grouped in columns that run at right angles to the surface. The deep layers of these columns have intercellular substances which are calcified and stain deeply even in decalcified H and E sections. This intercellular substance consists of collagenic fibers, embedded in a sulfated amorphorus type of intercellular substance.[3] In older animals these fibers form coarse bundles that run at right angles to the surface in the deep layers and become separated into smaller bundles which spread out in a fountain like fashion to run parallel with the surface.[3]

Below the deepest layers of chondrocytes, the calcified cartilage is replaced with bone which contains some canals with blood vessels in them. This bone is actually concellous or trabecular bone which has been laid down

on the calcified cartilage. "In H and E sections the cores of cartilage intercellular substance are blue, the bone covering them is pink or red, and the surface osteoblasts are blue."[3]

Adams describes osteoarthritis as a condition resulting from a periostitis and refers to it as ringbone, exostosis, and new bone growth. He classifies ringbone as high or low ringbone and articular or periarticular.[1] "High ringbone is new bone growth occurring on the distal end of the first phalanx and/or proximal end of the second phalanx. Low ringbone is new bone growth occurring on the distal end of the second phalanx and/or the proximal end of the third phalanx." "Articular ringbone means that the new bone growth involves the joint surface at the pastern or coffin joints. Periarticular ringbone means that the new bone growth is around the joint but does not involve the joint surface."[1]

Johnson refers to ringbone as any bony enlargment below the fetlock, whether a joint is involved or not. He feels the term might well be excluded from the scientific literature and replaced with names that indicate the anatomical structures involved.[4] "True ringbone has been referred to as osteoarthritis of the proximal or distal interphalangeal joint, and false ringbone to a periarticular periostitis of the involved phalanx."[4]

Adams uses the term ringbone but also, uses the terms osteoarthrosis, and hypertrophic or degenerative arthritis as synonymous with osteoarthritis.[1] Osteoarthrosis and degenerative joint disease are the most accurate terms since the disease is usually noninflamatory and is characterized by uneven joint spaces, variable amounts of lipping, and hypertrophic new bone growth around the joint.[1] "Sclerosis of the adjacent bone may be evident."[1]

The initiating factors are recognized as primary or secondary. Primary factors are related to intrinsic degeneration of articular cartilage underlying the development of the disease.[1] There are predisposing secondary

factors such as, trauma allowing osteoarthritis to supervene on other types of pre-existing damage to the joint such as traumatic or serous arthritis.[1]

Trauma is the most common initiating factor of osteoarthritis of the proximal interphalangeal joint area.[1,4] Stretching of the collateral ligaments of the joint, of the joint capsule attachments, and of the extensor tendon attachments will lead to periostitis.[1,4] Direct trauma such as wire cuts, hard blows, luxations to the area may also injure the periosteum.[1] Initial damage to the periosteum is followed by hemorrhage and formation of fibrous connective tissue but repetitive disruptions will result in the laying down of new bone which becomes visible radiographically.[1,4]

The periosteal reaction may involve the joint space and result in articular osteoarthritis which will interfer with joint movement. The articular osteoarthritis has also been described as resulting from uneven spacing of the articular surfaces of the pastern joint and insufficient height of the ridges dividing the articular surfaces on the proximal surfaces of the second phalanx.[1]

While stretching of the collateral ligaments and associated structures of the pastern joint is considered the true eitology of osteoarthritis, predisposing factors such as conformation, improper foot care, nutrition, and training managment play a very important role.[1,4,5] In addition, other pathological problems such as fractures, subluxations, and infections can indirectly lead to osteoarthritis.[1]

"Conformation can predispose a horse to excessive trauma on one area of a joint and lead to articular involvement and/or collateral ligament stretching or tearing. In base-narrow horses, for example, there is more weight borne on the lateral articular cartilage; the opposite is true with a base-wide conformation."[4] When a base-narrow or base-wide conformation exists in conjunction with toeing in or toeing out, the resulting rotating effect on

the joint will stretch or tear the collateral ligaments.[1] "Pasterns that are overly upright will result in increased concussion to the pastern joint." "Conformation is probably inheritable leading some authors (Strecher, 1962) to consider osteoarthritis in a similar manner."[1]

Nutrition has been a favorite field for theorizing on the courses of many equine lameness problems. The cause of osteoarthritis that results from osteoporosis and breakdown of subchondralbone is undetermined. "Inadequate intake of total nutrients or any given nutrient may cause nonspecific slowing of both cartilage proliferation and new bone formation in young animals and rarefaction of bone in adults."[4] Schneider lists faulty nutrition as a predisposing factor for ringbone.[5]

Metabolic bone disease which can be referred to as rickets, is primarily a disease of the epiphysis rather than the joint itself.[1,4] A deficiency or imbalance of calcium, phosphorus, and/or vitamins A, D, and C can cause the condition. Arthritis of the pastern, fetlock, carpus and tarsus can be due to stresses caused by conformational changes or deviations resulting from the epiphyseal changes in any of the leg bones.[1]

Horses feet should be trimmed every 4 to 6 weeks if used barefoot, and shoes should be reset every 4 to 6 weeks on horses that are shod. Shoes are reset more frequent on racing horses. The object of proper trimming is to make the shape of the foot and the angle of the foot axis as nearly normal as possible.[1]

The pastern foot axis is an imaginary line starting at the proximal end of the first phalanx, passing through the center of the second phalanx and dividing the two phalanges into equal parts, then at the cornary band continuing into the foot with the same angle to the ground surface.[1] The normal foot axis as viewed from the side should be 45 to 50 degrees in the front; and 50 to 55 degrees in the hind feet.[1] "Each horse has its own normal axis

of pastern and hoof and will not always fit the theoretically normal axis angle."[1]

If the foot or pastern axis is too steep, pathological changes will occur due to such conformation. As long as the angles of the pastern axis and of the foot axis are identical the foot axis angle should not be changed by trimming or shoeing for that will also create pathological changes.[1]

Adams states that long toe length increases the strain on the flexor tendons, suspensory ligaments and proximal sesamoid bones.[1] "With short toes and high heels, the center of the weight is posterior to the point of the frog."[1] This reduces the strain on the flexor and suspensory apparatus but increase concussion which is a factor conducive to ringbone, navicular disease, and traumatic arthritis of the fetlock.[1]

Fractures of the first and second phalanges are very common among cutting and barrelracing horses especially in the rear legs. Shoes with heel caulks predispose to phalangeal fractures because the caulks serve as an anchoring device while the weight is on the foot thus increasing the twisting action.[1]

When small chip fractures occur off of the first or second phalanx or one of these bones is split longitudinally they can be repaired by ASIF* compression technique.[1] If the fragments are to small for fixation, they should be removed.

Many of the phalangeal fractures are severely comminuted and involve the proximal interphalangeal joint surface. "When the damage to the pastern joint is severe, it is best to surgically ankylose the joint."[1]

Subluxation of the pastern joint usually causes a pulling of the

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*Association For The Study Of Internal Fixation

collateral ligaments, joint capsules, distal sesamodian suspensory apparatus, and other soft tissue structures and can cause tearing or rupture of these tissues.[1] Following luxations the periosteum is disturbed and periostitis and new bone growth occurs. "The joint space is also decreased and eventually will lead to natural ankylosis as a result of destruction of the articular cartilage."[1]

Infectious arthritis is caused by mechanisms such as direct open wounds into the joint including arthrocentesis or injections, metastatic infections, and extensions from neighboring areas of infection.[1] Severe injury such as sprains and intra-articular corticoids lower joint resistance and predispose to infections.[1] Metastatic infections are the most common and may spread from any focus of infection or by bacteremia. "It takes two to three weeks for radiographic changes to occur at which time the new bone growth is characterized by a sunburst effect."[1] Some cases have chronic progressive degenerative changes, and often end in ankylosis of the joint.

"If osteoarthritis of the proximal interphalangeal joint is articular in nature, the horse will be lame until the joint is ankylosed." "Ankylosis is the end result of a severe osteoarthritis, infectious arthritis, or fractures and severe injury to the articulation."[1] It is characterized by destruction of the articular cartilage, erosion of the joint surfaces, flattening of the underlying bone, and bulging of the joint by new bone growth.[1] "Too often, the joint refuses to ankylose; this results in massive deposits of new bone growth around the joint with a hairline articular space shown on radiographs."[1]

In cases of nonarticular osteoarthritis, removal of the new bone growth which is causing lameness by encroaching on adjacent soft structures is successful in about half the cases.[1]

Most methods of non-surgical treatment have been unsuccessful. This is

especially true with articular osteoarthritis.[1] Ankylosis has been shown to relieve the pain associated with osteoarthritis by preventing movement of the joint surfaces.[1,4,5,6,7,8,9,10] Ankylosis may be stimulated by surgically stripping the joint of its articular cartilage, after which the limb is placed in a plaster cast for eight to twelve weeks to allow complete ankylosis of the joint.[1,5] The use of ASIF cortical screws to aid in compression has been reported by some authors.[1,5,6,7]

In small animal surgery, arthrodesis has been reported in the elbow, carpus, stifle and hock.[8] Adams describes the use of arthrodesis for fusion of the distal intertarsal and tarsal metatarsal joints for treatment of degenerative osteoarthritis of these joints as well as for the proximal interphalangeal joint.[1] Fessler reported using a plate on the dorsal margin of the third metacarpal bone and first phalanx as a method of managing chronic or severe injuries of the fetlock.[10] Von Salis[6] first reported on the use of ASIF cortical screws for arthrodesis of the proximal interphalangeal joint and Johnson reported use of electrical microcurrent stimulation of the bony ends in the same joint.

Dr. Schneider reported using 3 ASIF screws placed parallel to the longitudinal axis of the foot in 22 clinical cases of arthrodesis. Eighteen of the 22 were found to be athletically or performance sound from follow-up study.[5] Dr. Wheat described the use of heavy Richards screws* in a crossed pattern for arthrodesis of the proximal interphalangeal joint.[7] The procedure worked well on the rear leg and produced a usably sound horse but in the front legs the horses showed some mechanical stiffness. He reported that the ASIF screws were not strong enough to hold without breaking in some instances even with an external cast support.[7]

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*Richards Manufacturing Company Inc., 1450 Brooks Rd., Memphis, Tenn. 38116

The basic principles involved in a surgical arthrodesis designed to reduce postoperative recovery time and external callus formation are:[8] (1) Removal of all articular cartilage and underlying subchondral bone by means of a high speed drill, osteotome, or bone curette. If any cartilage is left, bony union in that area will be delayed and result in incomplete or nonunion. (2) Rigid internal fixation of the bone surfaces. Inadequate immobilization will result in motion at the fusion site, causing loss of stability, implant failure, and delayed vascularization across the joint preventing new bone formation. (3) Incorporation of an autogenous cancellous bone graft will ensure the most rapid union and thus allow the speediest return to function. The graft serves as a scaffold for the growth of vessels and as an inducing factor. A small percentage of the osteogenic cells will survive, approximately 10 per cent. (4) The arthrodesis should be externally supported in a plaster splint for three to four weeks or until radiographic evidence of early fusion is seen. Schneider reports leaving the external cast on for an average of 23 days in arthrodesis of the proximal interphalangeal joint using internal ASIF cortical screws.[5] Other authors report 35 days,[9] 56 days,[6] and 70 days.[1]

Radiographic evidence of fusion is indicated by a decreased joint space and obliteration of the joint spaces with new bone growth.[1] Adams reported that there is radiographic obliteration of the joint space 6 months following an arthrodesis using external fixation only.[1] Guffy reports that the radiolucent joint space is normally obliterated as early as 30 days postoperatively in arthrodesis using ASIF compression technique.[11] Schenk's experiment on primary bone healing of an osteotomy of a dog's radius showed that the osteotomy line disappeared as early as 5 weeks.[12,13] There was a complete loss of the joint space on an electrically stimulated arthrodesis 74 days postoperatively, but still some areas of radiolucency

in the unstimulated control.[9]

During arthrodesis two bone fragments are produced which resemble the ends of fractured bones.[3,12,13] The blood vessels and soft tissue are traumatized and die back to areas of anastomosing blood vessels. The blood between the fragments soon forms a clot in and about the site of fracture or fragment ends. The osteocytes of the haversian systems die back for a certain distance from each side of a fracture line due to the destruction of the blood vessels.

A fracture is repaired by a growth of new tissue that develops around and between the ends of the fragments. This new tissue will form a bridge between the fragments so they are united.[3] Proliferation of osteogenic cells occurs in both periosteal and endosteal regions. The proliferation occurs rapidly and surrounds the fragments with an external callus especially with lack of rigid fixation. This callus grows so rapidly in some areas that the blood supply becomes inadequate and the osteogenic cells will differentiate into chondroblasts and chondrocytes.[3] As a result, cartilage develops in the outer parts of the callus. Its development should not be unexpected since the osteogenic cells are direct descendents of the cells of the perichondrium of embryonic bones, where they once formed cartilage.[3] Factors such as species, and movement also influence the differentiation.

Experimental studies have been done on laboratory animals, dogs, and larger animals to demonstrate the type of healing which occurs with rigid internal fixation.[3,12,13] The fragment ends were made using a fine osteotomy saw thus allowing the ends to be smooth and even enough to be brought into direct apposition and held rigidly through the healing period.

The healing between the ends was as follows:[3,12,13] The osteogenic cells and endothelial cells of the capillaries all die back for some distance

from the fracture line to the site where capillaries are anastomosing with functioning vessels. The osteocytes in the bone surrounding the haversian canals close to the fracture line die. Proliferation of osteogenic cells and capillaries occurs back from the fracture line. The osteogenic cells differentiate into osteoblast and build new haversian systems within the widened canals. This dual process advances to the fracture lines or bone ends. These osteons cross the ends and extend into the opposite fragment.

The fragment ends of a fracture or arthrodesis do not often end up as smooth and even so as to fit together in close apposition over their whole extents. Grant completed a study in which the fragment ends were not smooth or even for them to be fitted to achieve direct contact with each other.[3] Grant observed that osteons were formed on each side of the fracture lines but before there could be any attempt to cross the line they first had to fill the spaces between the fragments with new immature bone. This new bone merely glued the two bone ends together. The fracture or osteotomy line previously seen on radiographs was no longer apparent which can give a false impression of substantial healing of the so called primary type.[3] Substantial healing doesn't occur under these conditions until the whole internal area is remodeled by which new haversian systems or osteons peg one fragment directly into the other. Grant reported this process to extend as long as a year.[3]

If the gap between two bone fragments was too large or delayed union occurs then mesenchyme or connective tissue occupies the interfragmentary gap. This pattern is similar to fetal indirect osteogenesis or fetal intramembranous bone formation.[3,12,13] The mesenchymal cells differentiate into osteoblasts which cluster together to form centers of ossification and a self maintaining population of stem cells that proliferate to supply new osteoblasts to the region.[3] The stem cells and osteoblasts remain

closely applied to the margin of the bone already in the area with some of the cells proliferating and some differentiating into osteocytes to form beams of bone called spicules.[3] Well developed spicules that radiate out from the ossification centers are termed trabeculae.

Johnson compared the use of internal electrical microcurrent stimulation plus external cast fixation with external cast fixation only both being done on the same horse following articular cartilage removal.[9] On one horse the arthrodesed specimens were harvested at 35 days and evaluated histopathologically. The union of the unstimulated side consisted of a collagenous tissue with a small amount of fiber bone while the stimulated union consisted of trabecular bone and osteons.[9]

Wounds affecting the articular cartilage are divided into 1) those causing injury to the cartilage only, 2) those causing injury to both the cartilage and subchondial bone.[3] The former heals to some extent by assistance from synovial membrane cells or associated chondrocytes.

The cells involved in the repair of a wound which effects both articular cartilage and bone are osteogenic cells derived from the trabeculae of the cancellous bone which supports the cartilage and the connective tissue cells of the marrow that lies between the bony trabeculae.[3] The cells fill the defect with new bone, masses of cartilage, and fibrous tissue. A majority of the tissue becomes calcified and is not a good substitute for articular cartilage.[3]

Salter and Field made an experimental study which showed that passive motion of a joint improved the quality of cartilage repair in an articular cartilage defect.[3] They showed that degeneration of the articular cartilage occurred as soon as 6 days if a joint was immobilized in a forced position. The effects of compression interfere with the nutrition of the articular cartilage cells. The nutrition is dependent on diffusion through

the synovial fluid and then through the intercellular substances of the cartilage which is facilitated by movement.

Investigators have recognized the need to determine the mechanical strength of long bones for more than a century.[14] These tests have been needed for investigating the phenomena of fracture repair.

Variation in test duration have significant influence on observed results. Studies have demonstrated the variability in strength and rigidity characteristics that can be produced by variation of the time factor in testing. "Human tibias, for example, can absorb 45 percent more energy when broken at strain rates equivalent to trauma than when bones were broken over a period of several minutes."[14]

A study was undertaken to determine the most suitable configuration for loading of bones. Five criteria were chosen against which each loading configuration would be judged. These criteria were:[14] (1) The loading configuration must produce fractures similar to clinical fractures. (2) The loading configuration must subject the bone to equally severe loading conditions at every section along its length so as to be able to identify weak sections. (3) The loading mode must not be critically dependent upon bone geometry, in particular bone length, in terms of the severity of its effect. (4) The loading configuration must allow control of the rate of application of loads, so that the time condition produced in the test would be reproducible and preferably representative of those of normal trauma. (5) The loading configuration must result in a test apparatus which is relatively inexpensive and could be operated by persons with only ordinary skill in handling such mechanical equipment.

A bending loading configuration using two supports and a single load point is not satisfactory, since it fails to meet criteria 2 or 5.[14] The section which is directly below the loading point is subjected to the

maximum moment but other sections are subjected to lesser moments of varying degree. The only loading configuration which satisfies all the criteria is torsion.[14] Torsion load capacity is defined as the maximum amount of torque which may be applied axially to the bone before fracture occurs.[14] It is measured in cm-dyn or in-lb.

"Lameness is an indication of a structural or functional disorder in one or more limbs that is manifested in progression or in the standing position."[1] The diagnosis of lameness requires a detailed knowledge of the anatomy and physiology of the limbs, and there are cases of lameness where even the most experienced veterinarians differ in opinion.[1]

Proper examination included watching the horse coming toward the examiner, from the side view, and going away from the examiner.[1] The forelimb problems are best observed from the front and side views. It is very helpful to complete the examination on a hard surface and at a trotting gait.

MATERIALS AND METHODS

Eight geldings approximately 8 years of age ranging in weight from 450 to 550 kg., were purchased through the Animal Research Facility. A physical and lameness examination was completed on all eight horses. The criteria for acceptance for the project consisted of freedom from any abnormalties in the cardiovascular and respiratory systems which would increase anesthetic risks and the front limbs had to be free of any signs of lameness. The horses were randomly identified with numbers I-1 thru I-8 in the upper lip using a Franklin[A] equine tatto pliers. All the horses received an injection of Equiloid[B] and were dewormed using Parvex Plus[C] formula. Their feet, manes, and tails were trimmed prior to the start of the project.

Preoperative super-8 movies were taken of all the horses at a walk and trot from the side view. Radiographs taken preoperatively consisted of dorsal-palmar and lateral-medial views of both front proximal interphalangeal joints.

All horses had the left proximal interphalangeal joint operated on first and 60 days following that surgery the comparative procedure was completed on the right leg. The actual surgical procedure will be described in the following paragraph. The odd numbered horses had the criss-criss procedure completed on the left leg followed in 60 days by the parallel procedure on the right leg. The even numbered horses started with the parallel procedure on the left leg and then in 60 days the criss-criss procedure on the right. The horses were selected for surgery starting with I-1 and proceeding through I-8 consecutively.

The criss-cross procedure had two screws placed entering at the collateral eminence of the first phalanx diagonally criss-crossing in the

proximal interphalangeal joint and entering the second phalanx. The parallel procedure had three screws placed entering on the dorsal-distal end of the first phalanx and obliquely crossing the proximal interphalangeal joint but remaining parallel to the longitudinal axis of the limb and entering the palmar cortex of the second phalanx.

The day prior to surgery the selected limb was clipped from 8 cm. proximal to the metacarpophalangeal joint to the coronary band. The dorsal surface of the limb was shaved from the proximal end of the metacarpophalangeal joint to the coronary band. It was then scrubbed with organic iodide scrub[P] for ten minutes. The shaved area was wrapped in a sterile gauze dressing saturated with organic iodide solution[E] and secured in place as an orthopedic preparation using elastikon.[C]

On the day of surgery the selected horse was preanesthetized intravenously with acepromazine maleate[G] given at the rate of .08 mg/kg body weight. The horse's mouth was washed with water and he was strapped to the table with the selected leg on the outside. The 500 milliliter solution containing 3 gms of sodium thiamylal[H] and 25 gm of glycerol guiacolate[I] was used intravenously as an induction agent. Following induction the horse was placed in lateral recumbency intubated with a Coles[J] intratracheal tube, and maintained on halothan[K] from a semiclosed system gas machine.[L] The horse was given 3 gms of sodium bicarbonate[M] mixed with 3 liters of eltrad[N] solution per hour of surgery.

The selected foot was covered with sterile gloves which were taped into place at the coronary band. The sterile dressing was removed and the limb rescrubbed with an organic iodide scrub for five minutes. A pneumatic tourniquet[O] was applied above the carpus on the mid-radial area at 550 millimeters mercury pressure.

A plastic drape[P] was placed beneath the leg and over the top of the

down leg. The entire horse was then draped with cloth drapes to prevent contamination of the surgery site by body dust. A sterile adhesive drape[Q] was used to cover the leg distal to the fetlock joint. The plastic drape was then covered with a large cloth drape and the upmost leg allowed to rest on the down leg. The surgery leg was then covered with two large cloth drapes and final drape with a 7.5 by 12.5 cm opening. The opening of the latter had additional 25.0 cm by 30.0 cm towels placed at its edges and secured with towel clamps.

A large C-shaped incision was made over the dorsal surface of the proximal interphalangeal joint area, extending from the proximal one fourth of the first phalanx on the medial side, going laterally over the first phalanx then distally to 1 cm proximal to the coronary band. The incision curved distally and paralleled the coronary band. The skin and subcutaneous fascia was reflected medially exposing the common digital extensor tendon and the collateral ligaments of the proximal interphalangeal joint. An inverted V incision was made in the common digital extensor tendon starting at the distal border of the attachment of the dorsal branch of the suspensory ligament. The tendon distal to the inverted V incision was reflected distally along with the joint capsule, exposing the proximal interphal- joint. The collateral ligaments were severed and the joint was opened to allow full view of the entire articular cartilage.

A nitrogen powered stryker drill[R] with a 4.5 mm drill bit was used to loosen the articular cartilage on the first and second phalanges. The cartilage was removed down to the bleeding subchondral bone by using a bone curette. The joint was cleaned completely of blood and pieces of cartilage using sterile gauze pads. A shelf 5 mm wide and 5 mm deep was made with a chisel to seat the 4.5 mm drill and guide approximately 2.5 cm proximal to the joint and on the direct midline of the first phalanx. The drill was

directed through the distal end of the first phalanx in a direction that allowed as much purchase into the second phalanx as possible. As the hole was drilled the foot was held in maximum extension to achieve normal alignment of the first and second phalanges. Care was taken to assure that the screw and its alignment continued through the first phalanx and into the second phalanx in the midline direction. A 4.5 mm lag hole was drilled completely through the distal end of the first phalanx.

It was important to have the chuck of the drill as close to the metacarpophalangeal joint as possible to achieve good purchase of the screws in the second phalanx. After drilling through the distal end of the first phalanx, the first and second phalanges are then placed in maximum extension to align the proximal interphalangeal joint in its original anatomical position. A 3.2 mm drill guide was placed in the lag hole and a 3.2 mm drill bit was used to drill through the articular cortex and obliquely through the palmar cortex of the second phalanx.

After completion of the 3.2 mm hole, the lag hole was countersunk at its origin on the dorsal-distal part of the first phalanx to create a depression in which the screw head could be seated. This reduced angular stress on the screw head as it was tightened and seated. The length of the entire drill hole was measured and 2 mm was subtracted from the measurement to compensate for compression. The 3.2 mm hole was then tapped with a full thread cortical bone tap and a screw of appropriate length was then seated. Dorsal-palmar and lateral-medial radiographs were taken to substantiate the proper length and angle of the screw. The second and third screws were then placed following the same procedure as for the middle screw. The angle of the outer screws was determined by aligning the drill with the screw driver which was left in the middle screw. After three screws were placed, radiographs were again taken with the screw driver left in one of the outer screws

for purpose of identification. The radiographs were evaluated to confirm proper length and angle of the second and third screws.

The surgical procedure for the cross screw method was the same up to the point of drilling the lag holes in the first phalanx. Before placing the two phalanges in alignment, 4.5 mm holes were drilled in the first phalanges from the joint surface going out approximately 2.5 cm above the distal end in the area of the lateral and medial collateral eminences. The lateral hole was started dorsal-lateral to the intercondylar groove and the medial hole was started palmar-medial to the intercondylar groove. A drill bit was left in the lateral hole and was used as an aid in preventing the medial hole from entering its path. The two phalanges were aligned in maximum extension and the 3.2 mm guide placed in the lateral lag hole. A 3.2 mm drill was used to drill into the second phalanx. The depth was premeasured from the preoperative radiographs to prevent penetration of the coffin joint. After drilling the 3.2 mm hole, the lag hole was countersunk at its origin to create a depression in which the screw head could be properly seated. This reduced angular stress on the screw head as it was tightened and seated. The length of the entire drill hole was measured and 2 mm was subtracted from the measurement to allow for compression of the first and second phalanges. The 3.2 mm hole was then tapped with a full threaded cortical bone tap and a screw of appropriate length was seated to compress the two phalanges together. The medial lag hole was then finished with the same technique as above. After tightening the medial screw, dorsal-palmar and lateral-medial radiographs were taken to ascertain proper placement of both screws in relationship to the coffin joint and the structures palmar to the second phalanx.

In procedures where the screws either penetrated the coffin joint or the palmar surface of the second phalanx the problem screw was removed and

a shorter screw placed in the hole.

Following ascertainment of proper placement of screws in both procedures, the common digital extensor tendon and joint capsule were returned to their normal positions and the inverted V was sutured back with #1 polyglycolic[S] acid suture using a simple interrupted pattern. The subcutaneous fascia was sutured in place with #0 polyglycolic acid suture[S] using a simple continuous pattern. The skin was then closed with #1 monofilament nylon[T] in a horizontal mattress pattern. The incision was covered with sterile micropads[U] and wrapped with elastic gauze.[V] The leg was wrapped with elastikon over the elastic gauze and covered with stockinette[W] and cast padding.[X] Two layers of zoroc[X] cast were applied and then covered with sufficient layers of experimental cast[Z] #7 to encompass the foot and extend proximally to the carpus.

The above format was repeated on the opposite proximal interphalangeal joint using the comparative procedure. The odd numbered horses had the parallel procedure completed on the right leg and the even numbered horses had the criss-cross procedure completed on their right leg.

The horses were recovered in a padded stall and then placed in a straw covered cement floored stall 3 meters by 6 meters. Postoperatively the horses received 2 to 4 gms of phenylbutazone[A'] per day until they were bearing full weight comfortably which was usually 3 days or less. Penicillin (15,000 units per kg.) and steptomycin[B'] (14 gms per kg.) were given to the horses following the procedure on the second leg to reduce the risk of loosing a horse due to infection at that stage of the project.

Fifteen days postoperatively, the horses were anesthetized using 500 milliliter solution of 50 gms of glycerol guiacolate and 3 gms of sodium thiamylal intravenously following tranquilization using acepromazine maleate at .08 mg/kg body weight. The cast was split longitudinally on the dorsal

and palmar surfaces using an electric oscillating cast saw.[C'] Dorsal-palmar and lateral-medial radiographs were taken and evaluated to make sure the screws were still properly engaged, were not broken, or had any signs of radiolucency around them.

The skin sutures were removed and the leg rewrapped with elastic gauze and elastikon. The split cast was reapplied as close as possible to original fit and secured with two roles each of vetrap[D'] and zoroc.

The horses were recovered in a padded recovery stall and placed in a straw covered cement floored stall 3 meters by 6 meters for an additional fifteen days. At 30 days postoperative the cast was completely removed in standing position followed by dorsal-palmar and lateral-medial radiographs. The radiographs were evaluated for the amount of joint space obliteration and screw stability. A wrap of elastic gauze covered with elastikon was applied for an additional ten days. The horses received stall rest until 60 days postoperatively. The horses were at that time evaluated for degree of lameness at a walk, trot, and in a figure eight. Super-8 movies and dorsal-palmar and lateral-medial radiographs were taken for later review. The comparative procedure was completed on the right leg using the same format as for the left.

At 60 days postoperative on the right leg and 120 days postoperative on the left leg the horses had dorsal-palmar and lateral-medial radiographs taken of both front proximal interphalangeal joints, were clinically evaluated for lameness, and had super-8 movies taken of their gaits at a walk and trot from the side and front. The horses were euthanitized following the completion of the above procedures and the fused first and second phalanges were harvested for completion of the breaking test and histopathological examination.

The specimens were dissected free of soft tissue and taken to the

Department of Civil Engineering to be tested for breaking strength using the Reikle Universal Testing Machine.[E'] The specimens were measured for width(w) and thickness(t) at the fused proximal interphalangeal joint using a micrometer. The specimens were positioned as shown in figure (1) and had increasing pressure applied at a rate of 5 mm per minute until the point of breaking was reached which was indicated by acute stopping of the advancement of applied pressure. The kilograms of required applied pressure to break the fused first and second phalanges were recorded. The recorded breaking pressures and measured dimensions were used in the statistical analysis. Pin placement was judged to be statistically significant (alpha=.05) by the Analysis of Variance Procedure.[15,16]

Each specimen was split longitudinally with a table band saw and a 2 to 4 mm longitudinal section was cut from one half of the specimen. The sections were fixed in 10% buffered formalin[F'] for a minimum of 24 hours and then decalcified in RDO[G'] solution for 48 hours.

Each decalcified tissue specimen was trimmed to proper size (2 cm sq. x 4 mm thick), and given an identification number. Each piece of tissue was placed in a perforated metal cassette along with the identification number.

The specimens were paraffin embedded; and therefore, they must be dehydrated, cleared and infiltrated. This process was accomplished by use of an autotechnicon.[H'] The autotechnicon was equipped with a clock and metal timing disc which could be changed to suit individual timing needs. The autotechnicon was set to begin its cycle at 9:00 PM, at which time the dehydrating process begins.

There were twelve solutions in all on the machine and it was timed to remain in each solution one hour. The tissue was moved from 10% formalin through two changes each of 80% alcohol, 95% alcohol and 100% alcohol.

Xylene was used as a clearing agent. The hot paraffin baths were kept at 60°C. and the tissue remained in them for approximately two hours. At 8:00 AM, the tissue was placed in a vacuum infiltrator oven[I] for 15-20 minutes to remove any air bubbles and complete infiltration.

A tissue-tech embedding unit,[J] along with plastic embedding rings and stainless steel molds, were used for embedding. The plastic rings were labeled with the identification number and the tissue was embedded in 60°C paraffin with the mold and ring. The block was placed on a cold plate until the paraffin solidified at which time it was removed from the mold.

Paraffin embedded sections were cut on a rotary microtome.[K] The block was first coarse cut to remove the paraffin from the face and also to obtain a complete section. There was some drying of the tissue during processing, this was rectified by soaking the block in ice water before sectioning. The cold water hardens the paraffin which aided the sectioning. The sectioning was done at 6 microns, the sections were floated out on a warm water bath (45°-50°C) to which gelatin was added. The section was picked up on a slide which had been labeled with an identification number and placed in a warm air dryer (60°C). The slides were left in the dryer for a minimum of 15 minutes, removed and cooled, and were then ready for staining.

The regressive method of the hematoxylin-eosin stain was done on all the sections. The slides were placed in four changes of xylene for two minutes each. The sections were then hydrated through two changes of 100% alcohol, one change each of 95%, 80%, and 60% alcohols and into distilled water. The slides were left in each solution for two minutes. The sections were first over-stained with hematoxylin[L] (5 min.) and then partially decolorized in acid alcohol. The slides were then rinsed with water and blued in ammonia water. They were taken through two changes of water and

counter-stained with eosin[L'] (15 sec.). They were then dehydrated and cleared of alcohol through four changes of xylene.

A small amount of preservaslide[M'] was placed on a cleaned coverslip and the section was placed near the edge of the coverslip and inverted until the amounting media just touched it. The coverslip was picked up on the slide and any bubbles were gently eased out. The slides were laid flat in a slide folder until dry which was done for 24-48 hours in an incubator[N'] kept at temperatures not exceeding 50°C. The histological sections were then read and recorded for comparison of the surgical techniques.

DISCUSSION

The results of arthrodesis of the proximal interphalangeal joint in horses using a criss-cross (cruciate) pattern verses placement of three screws parallel with the long axis of the bone were compared. The comparison involved radiographs, gross and histopathology and motion studies. In addition, the fused first and second phalanges were subjected to breaking forces.

With both techniques the joint spaces were obliterated with new bone growth as indicated by loss of the radiolucent joint line by day 30 postoperative. A dorsal callus had started by the 30th day postoperative on 5 subjects involved with the parallel procedure versus 2 subjects involved with the cruciate procedure. The dorsal callus closed by postoperative day 60 on 6 of the subjects involved with the cruciate procedure and 3 of the subjects with the parallel procedure had closed. The dorsal callus did form on all of the subjects and was attributed to micromovement of the phalangeal ends. It started sooner with the parallel procedure, but did not close until after postoperative day 60. The earlier callus was thought to be due to the greater periosteal trauma caused on the dorsal-distal part of the first phalanx when placing the screws and its delayed closure was attributed to a lesser degree of micromovement with the parallel procedure. The dorsal calluses were smooth at 120 days in all subjects and there was no callus formation on any of the other perpherial surfaces of the ankylosed area. Exostosis around the screw heads was distributed equally between the two procedures and showed no consistent pattern. Horse number 1 had some periosteal reaction on the proximal palmar surface of the left first phalanx which was attributed to increased pressure on the distal sesamoid ligaments following loss of movement of the proximal interphalangeal joint.

Motion lameness evaluations were performed on postoperative day 60 and 120. The horses were sound at a walk for 5 of 7 horses when evaluating the cruciate procedure and all 7 horses when evaluating the parallel procedure. At a trot on the 60th day postoperative, 2 of 7 horses were sound in the leg with the cruciate procedure and 1 of 7 was sound in the leg with the parallel procedure. At 120 days postoperative the horses were sound at a walk and trot except for horse number 7 which was lame at a trot in the leg with the cruciate screws. These results would indicate that the parallel procedure had an advantage over the cruciate procedure at 60 days postoperative.

The gross pathological findings in the arthrodesed area were consistent with normal postoperative healing of incised tissue. The left distal interphalangeal joint of horse number 5 had an area lacking articular cartilage where one of the drill holes for the cruciate screws had penetrated. The screw was below the joint surface but the hole had not filled with any type of repair tissue.

The ankylosed first and second phalanges were subjected to breaking forces which concentrated the stress on the fused joint area. The fused joint broke in 6 out of the 14 arthrodesis, equally distributed between the two procedures.

Evaluation of the cruciate procedure, found 3 specimens breaking at the transverse prominence of the second phalanx and one at the condyle of the first phalanx. With the parallel procedure 3 specimens broke at the dorsal-distal end of the first phalanx through the area of screw penetration and one at the transverse prominence of the second phalanx. The breaking points in 8 out of 14 specimens indicate that the ankylosis can withstand stresses equal to those which are applied to the first or second phalanges. It is apparent that the screw holes weakened the phalanges below the breaking point of the ankylosis.

The geometric measurements of the proximal interphalangeal joint area were taken from the radiographs of the area and from the specimens following removal of all soft tissue. These values were used to calculate the bending stress and modified values of each specimen. Both values were used to reduce any error from variations in remaining soft tissue or from radiographic magnification.

Using the gross specimen measurements, the parallel procedure at postoperative day 60 had larger values for measured pressure, moment, modified pressure, and modified moment but smaller values for bending stress and modified bending stress. At postoperative day 120 the parallel procedure had larger values for bending stress and modified bending stress. The comparison of the values using the gross measurement indicate that the parallel procedure is stronger at 60 days than the cruciate procedure, however this advantage is lost at 120 days.

The statistical analysis completed using the gross specimen measurements where needed for calculations showed that the parallel procedure was significantly stronger than the cruciate procedure. The values for measured pressure, bending stress, moment and modified bending stress were significantly larger for the parallel procedure as compared with the cruciate procedure.

Using the radiographic measurements, the parallel procedure at postoperative day 60 had larger values for measured pressure, moment, modified pressure, and modified moment but smaller values for bending stress and modified bending stress. At postoperative day 120 the parallel procedure had larger values for modified pressure, and modified moments but smaller values for measured pressure, moment, bending stress, and modified bending stress. These results indicate that the parallel procedure was stronger at 60 days but that this advantage was narrowed by 120 days.

The statistical analysis completed using the radiographic measurements

where needed for calculations showed that the parallel procedure was significantly stronger than the cruciate procedure. The values for measured pressure, calculated moment, modified pressure, and modified moment were significantly larger for the parallel procedure as compared with the cruciate procedure.

The values for measured pressure and modified pressure are the most important for evaluation of the breaking strength of a structure such as the fused first and second phalanges.[17] These values were significantly larger for the parallel procedure when compared statistically with the cruciate procedure. The statistical analysis showed that the ankylosis increased in strength by 20 per cent from 60 days to 120 days postoperative.

The ankylosis was fused together by a new bone growth consisting of osteoid and calcified cartilage at postoperative day 60. At postoperative day 120, the fused area was starting to be remodeled by new osteons which were crossing between the two phalanges.

Both procedures can be used to ankylosis the proximal interphalangeal joint with consistency. The parallel was easier to accomplish, gave superior alignment of the first and second phalanges and had the least error of screw placement.

The alignment was superior with the parallel procedure because the middle screw was placed first and assured proper alignment of the first and second phalanges. The alignment was usually less than perfect with the cruciate procedure because one screw was tightened first and offset the two phalanges. Over drilling of the screw holes in the parallel procedure caused the holes to penetrate the far cortex of the second phalanx. The penetration was proximal enough to miss the attachment of the distal interphalangeal joint and navicular suspensory ligaments on the second phalanx. There was no gross damage seen from the over drilling in the parallel procedure. The

over drilling of the screw holes or improper angle of the lag holes in the cruciate procedure caused the screws to be misplaced in the distal interphalangeal joint or through the palmar surface of the second phalanx. That problem was solved by replacing the screw with one of a shorter length. The articular surface failed to heal in that area as indicated in the gross pathology review.

The damaged articular surface was not responsible for any motion lameness but could be a potential problem with athletic use. The improper angle of the lag holes caused the screw to be misplaced through the palmar surface of the second phalanx in the area for attachment of the navicular suspensory ligament.

The cruciate procedure would be useful for arthrodesis following a fracture of the transverse prominence of the second phalanx. The first and second phalanges could be fused using the cruciate but not the parallel procedure because the cruciate screws penetrate the second phalanx dorsal to the area at which that type of fracture occurs.

SUMMARY

The results of arthrodesis of the proximal interphalangeal joint in horses using a criss-cross (cruciate) pattern verses placement of three screws parallel with the long axis of the bone are compared. The comparison involved radiographs, gross and histopathology, and motion evaluations. In addition, the fused first and second phalanges were subjected to breaking forces.

That both procedures can be used for arthrodesis of the proximal interphalangeal joint with consistency is demonstrated by the results of the motion evaluation and direct examination of the fused area. The breaking procedures indicated that the fused joints were stronger or equal to the strength of areas penetrated by the cortical screws used in the internal fixation. The parallel procedure is significantly stronger than the cruciate procedure from a statistical analysis. The parallel procedure was easier to accomplish, gave better alignment of the first and second phalanges, and had the least error of screw placements.

The criss-cross procedure would be very useful in the repair of certain fractures of the second phalanx involving the transverse prominence which usually necessitates arthrodesis.

An arthrodesis using either procedure should be a satisfactory treatment for osteoarthritis and related problems of the proximal interphalangeal joint in horses, but the parallel procedure should create a superior union between the first and second phalanges during the first 120 postoperative days.

REFERENCES

1. Adams, O. R.: Lameness in Horses. Lea & Febiger, Philadelphia, Pennsylvania, 1-32 (1974):233-243-122-129-326-338-359-364.

2. Sisson & Grossman: Anatomy of The Domestic Animals. 4th Edition, W. B. Saunders Co., Philadelphia and London, P. 230, 1967.

3. Ham, Arthur W.: Histology. 7th Edition. J. B. Lippencott Company, Philadelphia and Toronto: 379-465 (1969).

4. Johnson, J. H.: Equine Medicine & Surgery. E. J. Catcott and J. F. Smithcors, eds., American Veterinary Publications, Inc., Wheaton, Illinois, (1972):546-548-497-501.

5. Schneider, J. E.: Journal of American Veterinary Association. Nov. 15, 1978.

6. Von Salis, B.: Internal Fixation in the Equine: Recent Advances and Possible Applications in Private Practice. Proceedings, 18th Annual Convention, Am. Assoc. Equine Pract. F. J. Milne, ed., (1972):193-218.

7. Wheat, J. D.: Personal Communications. January, 1978.

8. Olds, R. B.: Arthrodesis. Current Techniques in Small Animal Surgery. M. J. Bojrab, ed., Lea & Febiger, Philadelphia, Pennsylvania, (1975):549-562.

9. Johnson, J. E.: Ringbone: Treatment by Ankylosis. Proceedings, 20th Annual Convention, Am. Assoc. Equine Pract., F. J. Milne, ed., (1974):67-80.

10. Fessler, J. F. and H. E. Amstutz: Textbook of Large Animal Surgery. F. W. Oehme and J. E. Prier, eds., Williams & Wilkins Co., Baltimore, Maryland, (1974):300.

11. Guffy, Mark: Department of Surgery and Medicine; College of Veterinary Medicine, Kansas State University, Manhattan, Kansas 66502.

12. Schenk, R. and Willenegger, H.: Morphological Findings in Primary Fracture Healing. Symposium Biol. Hung., 7:75 (1967).

13. Schenk, Robert K.: Autorial Projection Prepared at The Learning Resources Center; College of Veterinary Medicine; Ohio State University (1977).

14. Burstein, A. H. and Frankel, V. H.: Journal of Biomechanics; Vol. 4, pp. 155-158 (1971).

15. Rubinson, Mike: Statistical Department; Kansas State University, Personal Communication. 1978-79.

16. Barr, A. J.; Goodnight, J. H.; Sall, J. P.; Helwig, J. T.: SAS Institute, Statistical Analysis System.

17. Cooper, Peter: Department of Civil Engineering; Personal Communications, Kansas State University, Manhattan, Kansas 66502.

FOOTNOTES FOR MATERIALS AND METHODS

A. Tatto Instruments., Franklin Co., Livestock Exchange Building, Denver, Colorado, 80216.

B. Equiloid, Fort Dodge Labs Inc., Fort Dodge, Iowa 50501.

C. Parvex Plus, UpJohn Co., Kalamazoo, Michigan 49001.

D. Prepodyne Scrub, West Chemical Products., New York, N.Y. 11101

E. Betadine Solution, The Purdue Frederick Co., Norwalk, Conn. 06856

F. Elastikon-elastic tape, Johnson & Johnson, New Brunswick, New Jersey 08903

G. Acepromazine Maleate, Ayerst Lab. Inc., New York, N. Y. 10007

H. Surital-Thiamylal Sol., Parke-Davis, Detroit, Michigan 48232

I. Glycodex-Guaifenesin - 50 mg/ml, Burns-Biotec, Omaha, Nebraska 68103

J. Coles Intratracheal Tube, Western Veterinary Supply, 351 West 45th Ave. Denver, Colorado 80216

K. Halothane, Halocarbon Lab., Inc., 82 Burlews Court, Hackensack, N. J. 07601

L. Gas Machine L.A., Frazer Sweatman Inc., 5490 Broadway, Lancaster, N. Y. 14086

M. NA Bicarbonate Injection USP., Travenol Labs., Inc., Deerfield, Illinois 60015

N. Eltradd I.V. 4000 Solution., Haver-Lockhart Lab., Bayvet., Division Cutter Laboratories Inc., Shawnee, Kansas 66201 - U.S.A.

O. Automatic Tourniquet, Waiter Kidde & Co., Inc., Belleville 9, New Jersey.

P. Plastic Drape, G. D. Manufacturing, Fort Collins Industrial Park, 1405 East Olive Court, Fort Collins, Colorado 80522.

Q. Band-Aid, Sterile Drape, Johnson & Johnson, New Brunswick, New Jersey.

R. Stryker Corporation, 420 Alcott, St., Kalamazoo, Michigan 49001.

S. Dexon - American Cyanamid Co., Peral River, New York 10965.

T. Block Monofilament Nylon, Pitman-Moore Inc., Washington Crossing, New Jersey 08560.

U. Micropad Dressing, 3M Co., 3M Center, St. Paul, Minnesota 55101.

FOOTNOTES (CON'T)

V. Sta-Tite, Chesebrouch-Ponds Inc., Hospital Products Division, Greenwich, Connecticut 06830.

W. Tubular Stockinette, American Hospital Supply, Division of AHSC, McGraw, Illinois 60085.

X. Sof-Rol Cast Padding, Johnson & Johnson, New Brunswick, New Jersey 08903.

Y. Zoroc, Resin Plaster Bandage, Johnson & Johnson, New Brunswick, New Jersey 08903.

Z. Cast #7, Bayvet, Division Cutter Laboratories Inc., Shawnee, Kansas 66201.

A'. Phenylbutazone-Med. Tech Inc., Elwood, Kansas 66024.

B'. Combiotic, Pizer Co.

C'. Cast Saw, Bone Stryker Saw, Orthopedic Frame Co., Kalamazoo, Michigan.

D'. Vetrap, 3M Co., 3M Center. St. Paul, Minnesota 55101.

E'. Riekle Testing Machine, Division of Ametek Inc., East Moline, Illinois.

F'. Fischer Scientific Co., Chemical Manufacturing Division. Fair Lawn, New Jersey 07410.

G'. RDO - DuPage Kinetic Laboratories, Inc., 29 W 550 N Aurora Road, Naperville, Illinois 60540.

H'. Technicon Instruments Corporation, 500 Benedict Ave., Tarrytown, New York 10591.

I'. Precision Scientic Corporation, Chicago, Illinois.

J'. Tissue Embedding Center, Division Miles Laboratories, Inc., 30 W 475 North Aurora Road, Naperville, Illinois 60540.

K'. American Optical Corp., 5437 Milton Parkway, Rosemont, Illinois 60018.

L'. Ames, Division Miles Laboratories, Inc., Elkhart, Indiana 46514.

M'. Ames Coverslipping Resin, Division Miles Laboratories Inc., Elkhart, Indiana 46514.

N'. Chicago Surgical and Electrical Co., Chicago, Illinois.

TABLE I

RADIOGRAPHIC EVALUATIONS

Procedure and leg	Horse number	Radiographic fusion[a] 30 days	Dorsal callus present 30 days	Dorsal callus closed 60 days	Smooth exostosis 120 days	Exostosis around screw heads	Involvement[b] P1
Cruciate Right	4	+	-	-	c	-	-
	6	+	-	+	c	-	-
	8	+	+	+	c	-	-
Cruciate Left	1	+	-	+	+	-	-
	3	+	-	+	+	+	-
	5	+	-	+	+	+	-
	7	+	+	+	+	+	+
TOTAL OF POSITIVE FINDINGS		7	2	6	4	3	1
Parallel Right	1	+	-	-	c	-	-
	3	+	+	-	c	-	-
	5	+	+	-	c	+	-
	7	+	+	-	c	-	-
Parallel Left	4	+	+	+	+	+	-
	6	+	-	+	+	+	-
	8	+	+	+	+	+	-
TOTAL OF POSITIVE FINDINGS		7	5	3	3	4	0

[a]Radiographic evidence of fusion as indicated by obliteration of the joint space with new bone growth.

[b]Periosteal new bone growth on the proximal palmar surface of the first phalanx.

[c]Specimen was harvested at 60 days postoperatively.

TABLE 2

LAMENESS EVALUATIONS

Procedure and leg	Horse Number	Sound at walk 60 days	Sound at trot 60 days	Sound at walk 120 days	Sound at trot 120 days
Cruciate Right	4	-	-	c	c
	6	+	+	c	c
	8	+	+	c	c
Cruciate Left	1	+	-	+	+
	3	-	-	+	+
	5	+	-	+	+
	7	+	-	+	-
TOTAL OF POSITIVE FINDINGS		5	2	4	3
Parallel Right	1	+	-	c	c
	3	+	-	c	c
	5	+	-	c	c
	7	+	+	c	c
Parallel Left	4	+	-	+	+
	6	+	-	+	+
	8	+	-	+	+
TOTAL OF POSITIVE FINDINGS		7	1	3	3

[c]Horses were euthanitized 60 days after surgery on the right leg.

TABLE 3

GROSS PATHOLOGY

Procedure and leg	Horse number	Breaking Location		
		At joint[d]	First phalanx[e]	Second phalanx[f]
Cruciate Right 60 days	4	-	+	-
	6	+	-	-
	8	+	-	-
Cruciate Left 120 days	1	+	-	-
	3	-	-	+
	5	-	-	+
	7	-	-	+
TOTAL OF POSITIVE FINDINGS		3	1	3
Parallel Right 60 days	1	+	-	-
	3	+	-	-
	5	-	+	-
	7	-	+	-
Parallel Left 120 days	4	-	+	-
	6	-	-	-
	8	+	-	+
TOTAL OF POSITIVE FINDINGS		3	3	1

[d]Break occurring at the area of the ankylosed proximal interphalangeal joint.

[e]Broke where the screws had penetrated the dorsal-distal part of the first phalanx.

[f]Broke where the screws had penetrated the flexor prominence of the second phalanx.

TABLE 4

SUMMARY OF MEASURED BREAKING PRESSURES, MOMENTS, AND BENDING STRESS CALCULATED FROM DIMENSIONS ON GROSS SPECIMENS

Procedure and leg	Horse number	Measured[g] pressure[kg]	Moments[kg][h]	kg/mm² Bending[i] stress
Cruciate Right 60 days	4	1240.9	21986.8	1.9
	6	1018.2	17897.0	1.8
	8	1211.4	21292.7	1.7
AVERAGE		1156.8	20392.0	1.8
Cruciate Left 120 days	1	1163.6	20552.1	1.8
	3	1938.6	34077.3	3.2
	5	1495.6	26286.3	1.5
	7	1068.2	18775.9	1.3
AVERAGE		1416.5	24922.9	1.9
AVERAGE ALL CRUCIATE		1286.7	22657.5	1.9
Parallel Right 60 days	1	1277.3	22559.1	1.7
	3	938.6	16498.9	1.8
	5	1500.0	26366.2	1.6
	7	1159.0	20080.0	1.7
AVERAGE		1218.7	21376.0	1.7
Parallel Left 120 days	4	1313.6	23090.4	2.2
	6	1418.2	24928.0	2.5
	8	1490.9	26206.4	2.1
AVERAGE		1407.6	24741.6	2.3
AVERAGE ALL PARALLEL		1313.2	23058.8	2.0

Footnotes - g, h, i - see page 44.

TABLE 5

SUMMARY OF MODIFIED PRESSURES, MOMENTS AND BENDING STRESS CALCULATED FROM DIMENSIONS ON GROSS SPECIMENS

Procedure and leg	Horse number	Modified[j] pressure[kg]	Modified[j] moments[kg]	Modified bending[j] stress kg/mm^2
Cruciate Right 60 days	4	1240.9	221986.8	2.3
	6	887.5	15599.0	2.1
	8	1336.3	23488.1	2.0
AVERAGE		1155.0	20428.0	2.1
Cruciate Left 120 days	1	1139.5	20125.4	2.2
	3	1812.3	31855.0	3.8
	5	2361.5	41509.1	1.7
	7	1352.0	23764.6	1.5
AVERAGE		1666.3	29313.5	2.3
AVERAGE ALL CRUICATE		1410.7	24870.8	2.2
Parallel Right 60 days	1	1481.2	26161.1	2.0
	3	750.1	13183.7	2.2
	5	2213.4	38905.0	1.9
	7	1237.0	21429.3	2.0
AVERAGE		1420.4	24919.8	2.0
Parallel Left 120 days	4	1217.6	21402.9	2.6
	6	1419.5	24950.7	2.6
	8	1616.3	28410.1	2.5
AVERAGE		1417.8	26811.6	2.6
AVERAGE ALL PARALLEL		1419.1	25865.7	2.3

Footnote - j - see page 44.

TABLE 6

SUMMARY OF MEASURED BREAKING PRESSURES, AND MOMENTS AND BENDING STRESS, CALCULATED FROM DIMENSIONS TAKEN FROM RADIOGRAPHS

Procedure and leg	Horse number	Measured[g] pressure[kg]	Moments[kg][h]	kg/mm^2 Bending[i] stress
Cruciate Right 60 days	4	1240.9	21986.8	3.2
	6	1018.2	17897.0	1.9
	8	1211.4	21292.7	2.7
AVERAGE		1156.8	20392.2	2.6
Cruciate Left 120 days	1	1163.6	20552.1	2.5
	3	1938.6	34076.3	5.0
	5	1495.5	26286.3	3.9
	7	1068.2	18775.9	1.9
AVERAGE		1416.5	24922.6	3.1
AVERAGE ALL CRUCIATE		1286.7	22657.4	2.9
Parallel Right 60 days	1	1277.3	22559.1	2.7
	3	938.6	16498.9	1.8
	5	1500.0	26366.2	1.8
	7	1159.0	20080.0	2.1
AVERAGE		1218.7	21376.1	2.1
Parallel Left 120 days	4	1313.6	23090.4	3.0
	6	1418.2	24928.1	2.5
	8	1490.9	26206.4	2.8
AVERAGE		1407.6	24741.6	2.7
AVERAGE ALL PARALLEL		1313.2	23058.7	2.4

Footnotes - g, h, i - see page 44.

TABLE 7

SUMMARY OF MODIFIED PRESSURES, MOMENTS, AND BENDING STRESS CALCULATED FROM DIMENSIONS TAKEN FROM RADIOGRAPHS

Procedure and leg	Horse number	Modified[1] pressure	Modified[1] moment	Modified[1] bending stress
Cruciate Right 60 days	4	1240.9	21986.8	3.8
	6	1416.4	24896.8	2.2
	8	1375.3	24174.1	3.2
AVERAGE		1344.2	23685.9	3.1
Cruciate Left 120 days	1	1390.6	24561.4	2.0
	3	1917.3	33701.3	5.9
	5	1987.2	34930.3	3.4
	7	1565.5	27518.7	2.2
AVERAGE		1715.2	30177.9	3.4
AVERAGE ALL CRUCIATE		1529.7	26931.9	3.3
Parallel Right 60 days	1	1526.5	26959.5	3.2
	3	1239.9	21793.4	2.2
	5	2124.0	37333.3	3.2
	7	1665.2	28848.5	2.4
AVERAGE		1638.9	28733.7	2.8
Parallel Left 120 days	4	1491.4	26215.0	3.5
	6	2078.5	26535.4	2.9
	8	2037.6	25805.0	3.3
AVERAGE		1872.7	35348.7	3.2
AVERAGE ALL PARALLEL		1759.8	32041.2	3.0

Footnote - 1 - see page 44.

TABLE 8

SIGNIFICANT STATISTICAL ANALYSIS
GENERAL LINEAR MODELS PROCEDURE
DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE
Gross subject dimensions were used where needed for calculations

Variable	Grouping[k]	Mean	N	Pin
P	ALPHA LEVEL=.05	DF=4	MS=37160.4	
Measured Pressure	A	2991.666667	6	P
	B	2639.166667	6	C
M	ALPHA LEVEL=.05	DF=4	MS=12067862	
Moment	A	52517.746479	6	P
	B	46490.000000	6	C
F	ALPHA LEVEL=.05	DF=4	MS=.0863576	
Bending Stress	A	4.207114	6	P
	B	3.681080	6	C
FQ	ALPHA LEVEL=.05	DF=4	MS=12.0925	
Modified Bending Stress	A	4.9784180	6	P
	B	4.3559443	6	C

[k]Means with the same letter are not significantly different.

TABLE 9

SIGNIFICANT STATISTICAL ANALYSIS
GENERAL LINEAR MODELS PROCEDURE
DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE
Using radiographic dimensions where needed for calculations

Variable	Grouping[k]	Mean	N	Pin
P	ALPHA LEVEL=.05	DF=4	MS=37160.4	
Measured Pressure	A	2991.666667	6	P
	B	2639.166667	6	C
M	ALPHA LEVEL=.05	DF=4	MS=12067862	
Moment	A	52517.746479	6	P
	B	46490.000000	6	C
Q	ALPHA LEVEL=.05	DF=4	MS=68810.9	
Modified Pressure	A	4004.929306	6	P
	B	3291.209284	6	C
MQ	ALPHA LEVEL=.05	DF=4	MS=22587974	
Modified Moment	A	70289.005403	6	P
	B	57958.289952	6	C

[k]Means with the same letter are not significantly different.

TABLES 4, 5, 6, 7

FOOTNOTES

[g]Measured breaking pressure is the pressure recording taken from the Reikle Universal Testing Machine which was required to break each fusion between the first and second phalanges.

[h]Moment is the kilograms-millimeters of pressure required to break the first and second phalanges derived from formula $M=\frac{P(1-a)a}{1}$.

[i]The bending stress is kilograms per square millimeters derived from formula $F=\frac{M=6m}{s\ wt^2}$.

See page for illustration of a, t, and w.

[j]The modified moments is calculated to eliminate the effects of geometric variations (a,t,w) on the measured failure loads (p), all failure loads are modified relative to one arbitrally selected specimen 0 as derived from formula Mod. P_1=measured $P_1 \frac{1-ao}{1-aj} \frac{ao}{ai} \frac{wi}{wo} \frac{ti^2}{to^2}$. The modified moments is then calculated from M=(modified P) $\frac{(1-a)a}{1}$ and bending stress is calculated from modified $f=\frac{6\ M(modified)}{wt^2}$.

If two specimens, A and B, have the same bending stress at failure,

$$f_A = f_B$$

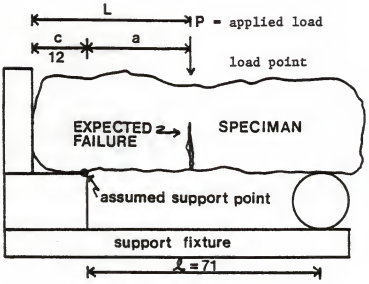
$$\frac{6\ M_A}{w_A t_A^2} = \frac{6\ M_B}{w_B t_B^2}$$

$$\frac{P_A(1-a_A)a_A}{lw_A t_A^2} = \frac{P_B(1-a_B)a_B}{lw_B t_B^2}$$

$$P_A = P_B \frac{1-a_B}{1-a_A} \cdot \frac{a_B}{a_A} \cdot \frac{w_A}{w_B} \cdot \frac{t_A^2}{t_B^2}$$

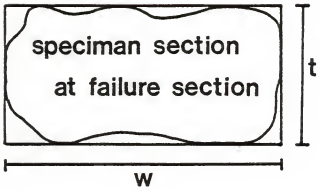
Measured pressure and modified pressure are the most important for evaluation of the breaking strength of a structure such as the fused first and second phalanges.[17]

SPECIMAN AND SUPPORT FIXTURE



l = fixed distance (71 mm)

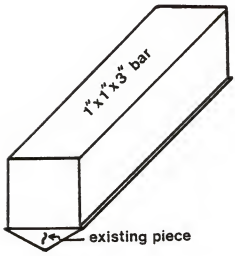
a = measured for each test



t (thickness) and w (width) measured for each specimen from gross specimen and radiographs

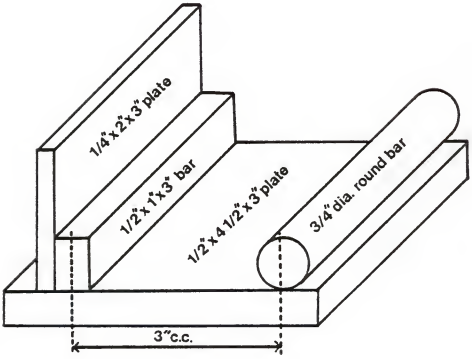
assumed to be equivalent to a rectangle

LOADING AND SUPPORT FIXTURES



LOADING FIXTURE

attached to moveable crosshead of testing machine



SUPPORT FIXTURE

rested on testing machine platform

Figs. 1 & 2. Methods of draping.

Fig. 3. C shaped skin incision.

Fig. 1

Fig. 2

Fig. 3

Fig. 4. Inverted V incision in common digital extensor tendon.

Fig. 5. Stryker drill in position to loosen articular cartilage.

Fig. 6. Use of a bone currette for removal of the articular cartilage.

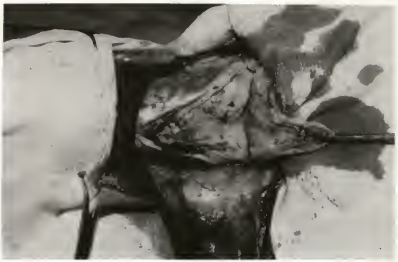


Fig. 4

Fig. 5

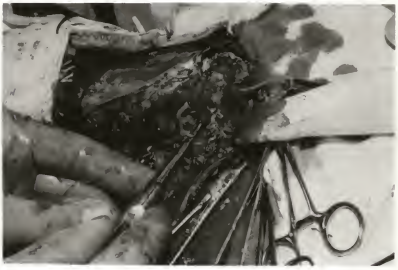


Fig.6

Fig. 7. Use of bone chisel to construct shelf to allow seating of the 4.5 drill bit and guide for drilling the middle lag hole.

Fig. 8. Shows the 4.5 drill through the lag hole in the distal end of the first phalanx.

Fig. 9. The foot is placed in maximum extension and a 3.2 mm hole is drilled through both cortices of the second phalanx.

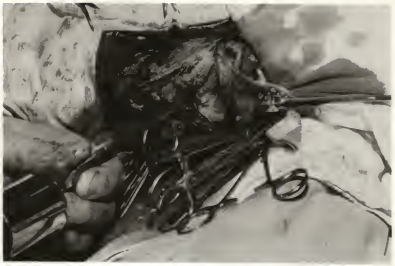


Fig. 7

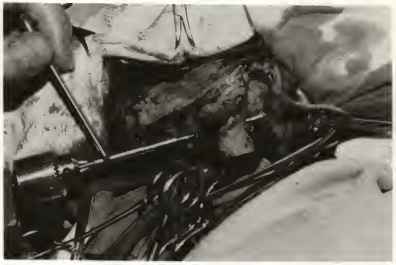


Fig. 8

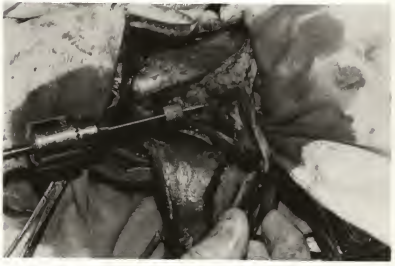


Fig. 9

Fig. 10. Countersinking the lage hole for proper seating of the middle screw.

Fig. 11. Measuring the depth of the entire drill hole between the first and second phalanges.

Fig. 12. Tapping the 3.2 drill hole with a 4.5 mm tap through a 4.5 mm guide.

Fig. 10

Fig. 11

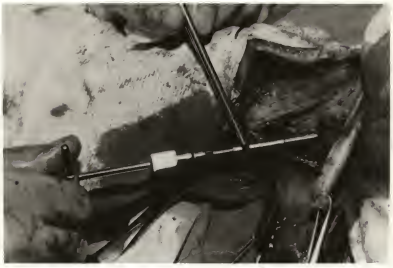


Fig. 12

Fig. 13. The 4.5 screw of the proper length is placed and tightened to lag the first and second phalanges together.

Figs. 14 & 15. Intraoperative radiographs are taken to ascertain proper placement of the middle screw.

Fig. 13

Fig. 14

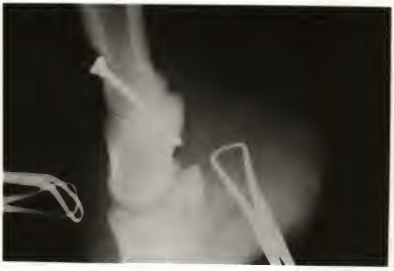


Fig. 15

Fig. 16. Placement of the medial and lateral screws using a screw driver handle placed in the middle screw as a guide for proper placement.

Figs. 17 & 18. Radiographs to ascertain the proper placement of the outer two screws.

Fig. 16

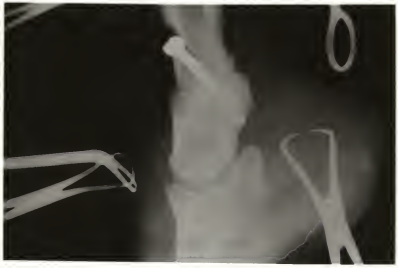


Fig. 17

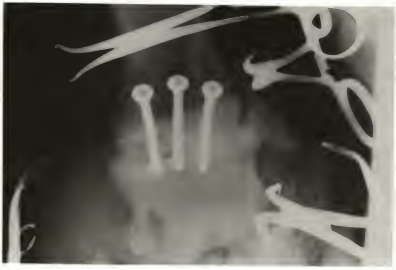


Fig. 18

Fig. 19. Demonstrates the proper placement of the 4.5 mm lag holes in the first phalanx for the cruciate procedure.

Fig. 20. The foot is placed in maximum extension and the 3.2 drill hole is made in the second phalanx.

Fig. 21. A 4.5 mm tap is used for tapping the 3.2 mm drill hole in the second phalanx following countersinking and measuring.

Fig. 19

Fig. 20

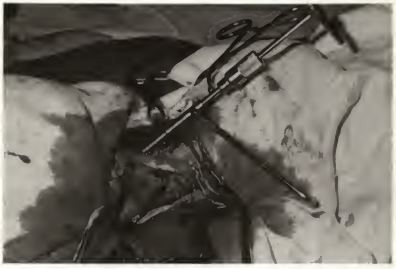


Fig. 21

Figs. 22 & 23. The first screw is placed and tightened to compress the first and second phalanges. The second 3.2 drill hole is drilled, countersunk, measured and tapped.

Fig. 24. The second screw is placed and tightened to completely compress the first and second phalanges.

Fig. 22

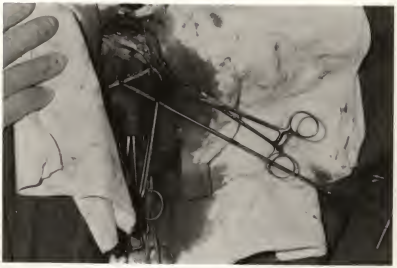


Fig. 23

Fig. 24

Fig. 25. Intraoperative radiograph showing one of the cruciate screws penetrating the palmar surface of the second phalanx due to improper alignment of its lag hole in the first phalanx.

Figs. 26 & 27. Radiographs showing one of the cruciate screws penetrating the distal interphalangeal joint.

Fig. 25

Fig. 26

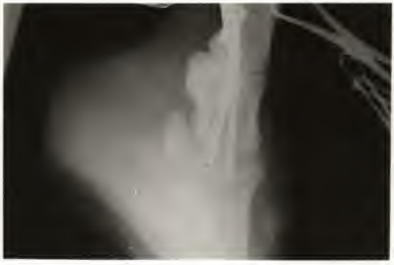


Fig. 27

Fig. 28. Suturing the common digital extensor tendon using a single interrupted pattern of number 1 or 2 polyglycolic acid suture.

Fig. 29. The skin is sutured using number 1 nylon in an interrupted horizontal pattern.

Fig. 30. The foot encompassed in a cast for external support.

Fig. 28

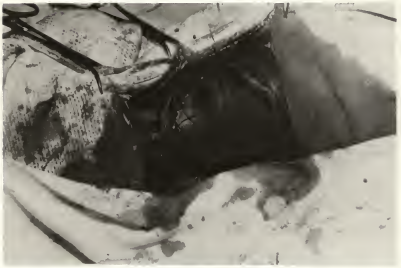


Fig. 29

Fig. 30

Figs. 31 & 32. Radiographs taken on day 15 postoperative to evaluate the arthrodesis. These radiographs demonstrate the radiolucent joint line following the arthrodesis.

Fig. 33. Radiographs at day 30 postoperative showing obliteration of joint space with new bone growth.

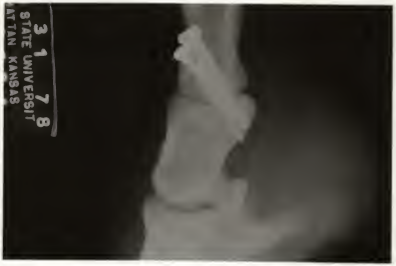


Fig. 31

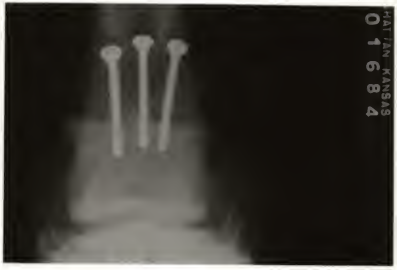


Fig. 32

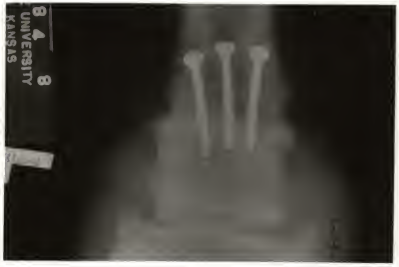


Fig. 33

Fig. 34. The dorsal callus is started to form at 30 days.

Fig. 35. Periosteal reaction on the proximal palmar surface of the first phalanx in horse no. 1.

Figs. 35 & 36. Radiographs showing that the dorsal callus has closed.

Fig. 34

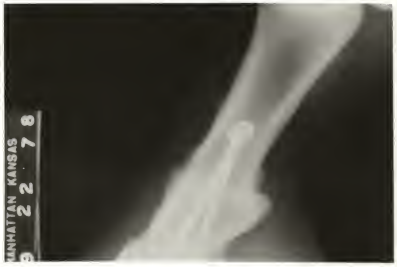


Fig. 35

Fig. 36

Fig. 37. Press and specimens.

Figs. 38 & 39. Histopathology sections of fused area.

Fig. 37

Fig. 38

Fig. 39

APPENDIX

Personal communications used as additional guidance and project direction.

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COMPARISON OF TWO SURGICAL PROCEDURES FOR THE ARTHRODESIS OF THE PROXIMAL INTERPHALANGEAL JOINT IN HORSES

by

ROGER M. GENETZKY

B.Sc. Kansas State University, 1970
D.V.M. Kansas State University, 1972

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Surgery and Medicine

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

ABSTRACT

Ankylosis of the proximal interphalangeal joint has been proven effective in the relief of pain and lameness associated with osteoarthritis of the joint. While ankylosis can be accomplished naturally, surgical arthrodesis will shorten the time necessary for fusion to occur and thus minimize extra articular exostosis. Five techniques have been described - 1) Placement of cross screws, 2) Placement of longitudinal screws, 3) Placement of foot in cast, 4) Dorsal plating, 5) Electrical current therapy, all in combination with destruction of the articular cartilage. The question then arises which of the internal fixation techniques is most desirous and produces the strongest fusion. The investigation was designed to compare placement of cross or cruciate screws with the placement of three parallel longitudinal screws as a means of arthrodesis in the pastern joint.

The results of arthrodesis of the proximal interphalangeal joint in horses using a criss-cross or cruciate pattern versus placement of three screws parallel with the long axis of the bone were compared. The comparison involved radiographs, gross and histopathology, and motion studies. In addition, the fused first and second phalanges were subjected to breaking forces.

That both the procedures can be used for arthrodesis of the proximal interphalangeal joint with consistency was demonstrated by the results of the motion evaluation and direct examination of the fused area. The breaking procedures indicated that the fused joints were stronger or equal to the strength of areas penetrated by the cortical screws used in the internal fixation. The parallel procedure was significantly stronger than the cruciate procedure from a statistical analysis. The parallel procedure was easier to accomplish, gave better alignment of the first and second phalanges, and had the least error of screw placements.

The criss-cross procedure would be very useful in the repair of certain fractures of the second phalanx involving the transverse prominence which usually necessitates arthrodesis.

An arthrodesis using either procedure should be a satisfactory treatment for osteoarthritis and related problems of the proximal interphalangeal joint in horses, but the parallel procedure should create a superior union between the first and second phalanges during the first 120 postoperative days.