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Injury to Synovial Structures

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Wounds involving synovial structures, including joints, tendon sheaths, and bursae, are common injuries in horses [1]. The most commonly affected structures include the navicular bursae, distal and proximal interphalangeal joints, metacarpal or metatarsal phalangeal joint, digital tendon sheath, carpus, tarsocrural joint, calcaneal bursa, and tarsal sheath [1]. Knowledge of anatomy is important to confirm or rule out synovial involvement. Early intervention and treatment provide the best opportunity to reduce bacterial contamination and secondary long-term sequelae of synovial sepsis. Early recognition and intervention can often result in a good prognosis, whereas delayed treatment can result in life-threatening or career-ending conditions [2]. This article focuses primarily on synovial contamination by means of wounds and is intended to be a review of the diagnosis, pathogenesis of infection, treatment options, and prognosis of traumatic injuries to synovial structures. In general, septic arthritis and septic tenosynovitis are similar diseases and share similar clinical signs, diagnosis, and treatment. Individual and select cases are discussed.

Pathogenesis

Lower limb wounds are more likely to become infected as a result of environmental exposure and limited soft tissue coverage. Bacterial infection induces a synovial inflammatory response [3,4]. Neutrophils, monocytes, and other inflammatory mediators are attracted to the synovial space in an attempt to eliminate the infection [3,5]. As neutrophils phagocytize the foreign material, they release destructive enzymes and chemoattractants, such as collagenases, cytokines (interleukin [IL]-1), and tumor necrosis factor (TNF). This inflammatory response results in alterations in normal

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cell metabolism, reduced proteoglycan production, deposition of fibrin within the synovial space, and release of matrix metalloproteinases (MMPs) [3,5]. The physical effects on the synovial environment that occur as a result of this inflammatory reaction include increased intrasynovial pressure (puncture wounds), accumulation of fibrin (pannus), degradation of hyaluronan, and depletion of proteoglycans within the articular cartilage. As the duration of infection and inflammation becomes chronic, the synovial membrane may become hypertrophic; undergo vascular proliferation, thrombosis of synovial vessels, and pannus formation; and develop fibrosis of the joint capsule [1,6,7]. This can result in permanent damage to the synovial structure and cartilage.

Diagnosis

History and physical examination

An accurate history is important in determining the source and duration of the injury. Acute synovial wounds (<6–8 hours) may result in contamination of the synovial structure without developing a fulminant infection. Wounds introducing bacteria into a synovial structure for longer than 6 to 8 hours (chronic) have enough time to establish synovial infection (Fig. 1) [1,8]. These wounds present a treatment challenge. The prognosis depends on the ability to eliminate infection and effectively disrupt the inflammatory cycle that is harmful to bone, cartilage, and tendon [9]. The prognosis depends on the wound type, location, and longevity.

In acute injuries or in cases of large open wounds, the horse may initially show minimal lameness because of the lack of established intrasynovial

Fig. 1. Palmar pastern laceration extending into the digital tendon sheath resulted in severe lameness, continued drainage, and purulent exudate from the sheath.

pressure or inflammation. As untreated wounds become chronic, however, lameness can rapidly progress to severe and often results in poor weight bearing. Typically, the synovial structure (joint, tendon sheath, or bursa) has marked effusion with accompanying soft tissue heat, swelling, and pain on palpation and manipulation. Usually, vital signs are normal; however, tachycardia and tachypnea may be observed when horses are in extreme pain. The horse may or may not have leukocytosis and hyperfibrinogenemia and may or may not be depressed, febrile, and anorexic.

Wound preparation

When lacerations occur near a synovial structure, it is essential to determine if communication exists between the wound and surrounding joint, tendon sheath, or bursa. Before exploration of the wound, the wound edges should be clipped of all hair and debris using a sterile water-soluble lubricating gel (Surgilube Sterile Bacteriostatic lube) or a sterile saline–soaked gauze in the wound bed to prevent contaminates, such as dirt and hair, from entering the wound and to facilitate their removal. Strict aseptic technique should be used in all cases until synovial involvement can be ruled out. The wound should be aseptically cleaned with a combination of sterile saline (0.9% sodium chloride [NaCl]) and an antiseptic solution. Aggressive lavage with isotonic saline (0.9% NaCl) reduces bacterial numbers in wounds, with minimal adverse effects on tissues. Isotonic saline provides a fluid medium that neither causes cells to swell, as when using tap water, nor to crenate, as when using hypertonic solutions [2]. To be most effective at reducing bacterial numbers and removing foreign particles and devitalized tissue, irrigation should be delivered at greater than 8 psi and less than 15 psi. Several fluid pumps are available; however, a practical alternative to mechanical pumps is syringe irrigation. A 35-mL syringe and 19-gauge needle provide irrigant pressure of 8 psi and reduce surface bacterial counts 100-fold [10]. Once the wound is adequately cleaned, digital exploration (with sterile gloves) should be performed to determine potential structures involved (ie, exposed bone or joint, soft tissue involvement, presence of foreign material deeper in the wound). A sterile teat cannula or malleable probe is useful for exploration in puncture wounds and deep penetrating wounds to help determine the direction and depth of wound tracts.

Diagnostic modalities

If synovial involvement cannot be confirmed after digital exploration of the wound, several diagnostic modalities can be used to help confirm or rule out synovial penetration. It is important to obtain a synovial fluid sample in all cases of potential synovial penetration, because the synovial fluid analysis can aid in the diagnosis of sepsis and help to provide a therapeutic plan. The synoviocentesis (of a joint, sheath, or bursa) should be performed at a site distant from the wound in nontraumatized tissues. The area should be aseptically prepared and sampled. After collection of a sample, the needle should remain within the joint, sheath, or bursa and a large volume of saline (0.9% NaCl) or lactated Ringer's solution (LRS) should be infused into the synovial structure. If the structure holds pressure, it is likely not penetrated. If fluid exits the wound, however, synovial communication is confirmed. If the fluid collected grossly looks contaminated (cloudy, turbid), antibiotics should be infused before withdrawal of the needle. Antibiotics may be injected into the structure after distention.

Cytologic evaluation of synovial fluid samples is probably the single most useful test in evaluating a synovial structure with suspected infection [11]. Normal synovial fluid generally contains fewer than 500 nucleated cells/μL, with mononuclear cells being the predominant cell type (macrophages and lymphocytes) [11]. A total nucleated cell count exceeding 30,000 cells/μL and a total protein concentration greater than 4.0 g/dL with greater than 90% neutrophils are indicative of infection [12]. Infections within tendon sheaths and bursae may result in more variable changes in synovial fluid nucleated cell and total protein values (generally lower than those of joints) [1].

Radiographic evaluation of the affected structure is a useful means to obtain information, such as soft tissue swelling, presence of radiopaque foreign material, and fracture of surrounding bone. This is particularly important if there are lacerations to the calcaneal bursa and the tarsal sheath, wherein concurrent injury and osteomyelitis of the tuber calcanei and sustentaculum tali can develop. A flexed proximoplantar-to-distoplantar tangential (skyline) view of the tarsus should be taken to evaluate these areas. In chronic septic processes, radiographic evaluation may confirm or rule out concurrent osteomyelitis of the surrounding bone.

Contrast radiography can assist in diagnosis of synovial involvement. Navicular bursa penetration after a nail wound to the solar aspect of the foot may be difficult to determine by physical examination and plain radiography. Contrast radiography is helpful in determining wound involvement of tendon sheaths and other bursae (Fig. 2).

Ultrasonographic examination is a useful diagnostic modality, particularly in acute and chronic septic tenosynovitis. It can provide further evidence of sepsis by identifying excess fluid, fibrin formation, fibrous adhesion formation, and connective tissue integrity. Ultrasound may identify foreign material introduced by means of traumatic wounds. It may also guide fluid collection for synovial fluid analysis. Introduction of gas into deeper tissues may occur in acute traumatic wounds, limiting the effectiveness of this modality in these cases.

Therapeutic plan

Once synovial involvement has been confirmed, an appropriate therapeutic plan must be initiated. Factors that determine treatment of synovial injuries include duration of the wound, contamination of the wound, other

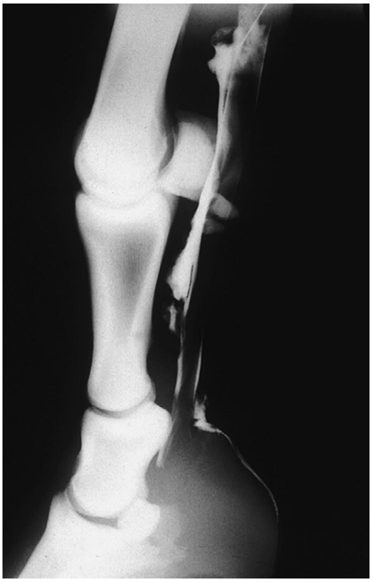

Fig. 2. Contrast material has been injected into the digital flexor tendon sheath and is exiting the wound at the level of the pastern, confirming penetration and communication with the tendon sheath.

structures involved, expectation of outcome and prognosis, and financial capabilities of owners. Treatment of septic arthritis or tenosynovitis is aimed at rapid elimination of the infection to minimize structural damage and fibrous adhesion formation [13]. The principles for treatment of infection for joints and tendon sheaths are similar; therefore, the following treatments are intended to apply to septic arthritis and tenosynovitis.

Identification of the causative organism(s) is important in the management of synovial infections. Although bacteria cannot always be isolated from synovial fluid, failure to isolate an organism from the synovial fluid does not rule out infection as the diagnosis [14]. It has been suggested that culturing the synovial membrane or fibrin results in greater probability of a positive culture. In one study in which synovial fluid and synovial membrane samples were submitted, however, growth was obtained from the synovial fluid in 16 (94%) of 17 joints, whereas growth was obtained from the synovial membrane alone in only 1 (6%) of 17 joints [11]. In general, infections that occur as a result of traumatic wounds generally tend to be polymicrobial because of environmental contaminates. In a retrospective study of 192 adult horses with septic arthritis or tenosynovitis, most of the bacterial isolates were aerobic and included Enterobacteriaceae, streptococci, staphylococci, other gram-negative and gram-positive bacteria, and miscellaneous isolates [15]. Another study found that *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa* were the most commonly isolated organisms in horses with infectious arthritis [11]. Although a positive culture is beneficial in directing antimicrobial therapy, it should not be solely relied on for a definitive diagnosis. Regardless of whether a positive culture is obtained, if clinical evaluation, synovial fluid analysis, and other diagnostic tests suggest an infectious process, appropriate aggressive treatment must be implemented.

Systemic and local antimicrobial therapy

Systemic antimicrobial and anti-inflammatory therapy

Systemic antimicrobials are recommended for all horses with acute or chronic synovial injuries [1]. Although an appropriate antibiotic regimen can be implemented based on the results of culture and sensitivity testing of an organism, one should not prolong beginning antibiotic therapy while awaiting results. The horse should be placed on broad-spectrum antibiotics immediately after obtaining a synovial fluid sample for culture. Antimicrobials can be tailored based on the results of culture and sensitivity testing. The most commonly used drugs include penicillin (potassium penicillin, 22,000 U/kg administered intravenously every 6 hours or procaine penicillin G, 22,000 U/kg administered intramuscularly twice daily) combined with gentamicin (6.6 mg/kg administered intravenously every 24 hours). Other drugs or drug combinations, such as penicillin and amikacin (15–25 mg/kg administered intravenously every 24 hours); cefazolin (11 mg/kg administered every 8 hours); and gentamicin, ceftiofur (both administered intravenously or intramuscularly at a rate of 1 mg/lb twice daily), and enrofloxacin (5–7.5 mg/kg administered intravenously every 24 hours), can be used, however. In combination with other treatments (which are discussed elsewhere in this article), broad-spectrum parenteral (often intravenous) antibiotics are typically recommended for 7 to 10 days. If the horse is responding favorably, it may be switched to an oral antibiotic for an additional 2 to 4 weeks depending on the severity of the infection and wound and clinical progression. Typical oral antibiotics used include trimethoprim-sulfa, 960 mg (15 mg/lb administered twice daily); doxycycline, 100 mg (11 mg/kg administered twice daily); and enrofloxacin (7.5 mg/kg administered every 24 hours). In addition to systemic antimicrobials, horses may be placed on nonsteroidal anti-inflammatory medications. The typical drug of choice is phenylbutazone (2.2–4.4 mg/kg administered intravenously or orally daily). Other choices include flunixin meglumine (1.1–2.2 mg/kg administered intravenously or orally daily), ketoprofen (2.2 mg/kg administered intravenously daily), or carprofen (0.7 mg/kg administered orally daily).

Intra-articular or intrathecal antimicrobial therapy

Resolution of infection is improved when an appropriate antibiotic is delivered to infected tissues in concentrations greater than the minimum inhibitory concentration (MIC) [16]. Synovial vascular injury, ischemia, necrosis, and pannus formation can all occur in severe or chronic synovial wounds and markedly limit the delivery of systemically administered antibiotics to the synovial membrane. This limitation has led to the development of alternative techniques of antibiotic delivery. Intra-articular delivery of gentamicin was originally thought to be too irritating in equine joints [17]; however, it was later shown to cause minimal inflammation in normal equine joints [18]. Synovial fluid concentrations after a single intra-articular injection of gentamicin are 10 to 100 times greater than those achieved with intravenous administration [19], and *E coli* infection was effectively eliminated in an experimental model of septic arthritis using intra-articular therapy [20]. Based on these studies, intra-articular antibiotic treatment of synovial infections has become widely used. Intra-articular amikacin, an alternative aminoglycoside, has become a more favorable intra-articular drug because of its similar but broader spectrum of activity. The typical dose should not exceed the systemic dose, and the frequency of administration should be every 24 to 48 hours. When possible, the choice of antimicrobial should be based on cultured organism antibiograms.

Indwelling catheter and continuous intrasynovial antimicrobial infusion are current treatment modalities that can complement more commonly used treatments for septic arthritis or tenosynovitis. Placement of an ingress fenestrated drain in combination with open arthrotomy incisions allows daily lavage through the synovial cavity and administration of antibiotics [21]. In a recent study, a commercially available continuous infusion system (Joint Infusion System, Mila International, Florence, Kentucky) was used for intrasynovial antimicrobial delivery in horses with septic synovitis. The mean daily dose of gentamicin delivered by means of the infusion system was 1.8 mg/kg (0.08 mg/lb), and the mean daily dose of amikacin was 5.5 mg/kg (2.5 mg/lb) [22]. Intrasynovial levels of antimicrobials (gentamicin and amikacin) in this study were greater than 50 times the MIC for common equine pathogens, and 93% of synovial infections resolved [22]. In another study, a balloon constant rate infusion system (On-Q PainBuster post-op pain relief system; I-Flow Corporation, Lake Forest, CA) was used for delivery of antimicrobials in horses with septic arthritis, septic tenosynovitis, and contaminated synovial wounds. Each horse underwent synovial lavage with arthroscopic, tenoscopic, or through-and-through needle lavage, and the infusion system was placed at the time of lavage. A third-generation cephalosporin (2 g) or an aminoglycoside (2–3 g) was used to deliver an antimicrobial at a rate of approximately 100 mg/h. Thirteen of the available 16 horses for which follow-up was available were reportedly sound [23]. The use of intra-articular or intrathecal indwelling drains and constant infusion systems seems to be beneficial in treating synovial infections. They allow a simpler means of antimicrobial delivery and maintain high antimicrobial levels within the synovial structure. Additionally, they provide an opportunity for antimicrobial delivery in such locations as the stifles, elbows, and bicipital bursa, wherein regional limb perfusion has not been possible [22]. If an indwelling catheter or infusion system is used as an adjunctive treatment, it should always be treated in an aseptic manner and a sterile dressing should be maintained to limit ascending infection risk.

Regional limb perfusion

Regional intraosseous and intravenous limb perfusion techniques achieve high concentrations of antimicrobials in synovial fluid and bone and are effective in clinical and experimental infections [24,25]. Regional intravenous perfusion involves delivering an antibiotic under pressure to a selected region of the limb through the venous system [16], whereas regional intraosseous perfusion involves placement of a cannulated bone screw into the bone proximal to the infected synovial structure. Both techniques can be performed in an anesthetized or standing sedated horse by placing a tourniquet above the level of injury (or above the cannulated screw) for distal limb injuries or above and below the injury (for the carpus or hock). During intravenous perfusion, injection of a diluted antibiotic solution under pressure distends the venous vasculature and the increase in hydrostatic pressure allows diffusion throughout the tissues below or between the tourniquets [24,26]. It is performed by placing a small-gauge butterfly catheter or a small-gauge intra-arterial catheter into a vein and infusing the diluted solution of antimicrobial slowly over a period of 3 to 5 minutes. For both techniques, the tourniquet should remain in place for a 30-minute period to prevent systemic absorption of the drug, thus maximizing local tissue concentrations (Fig. 3) [1]. The typical antimicrobials and doses selected are similar to those previously described for intra-articular use and are diluted into 30 to 60 mL of sterile saline. In one study comparing intraosseous versus intravenous delivery of amikacin in equine tarsocrural joints, a greater concentration of amikacin was achieved in the synovial fluid after intravenous perfusion and was technically easier to perform [25]. Both techniques produced local antibiotic concentrations that exceeded the MIC for gentamicin and amikacin within the synovial fluid and bone, however [1,24–26].

Antimicrobial-impregnated polymethylmethacrylate

Polymethylmethacrylate (PMMA) is a high-density polymer formed by combining a fluid monomer and a powdered polymer. When an antimicrobial is added to this mixture, it becomes suspended in the polymer as it hardens [1,27]. The antibiotics incorporated in PMMA beads are released in a bimodal (rapid and slow) manner [21,27]. Rapid elution of the antimicrobial takes place, usually within the first 24 hours, and the subsequent elution rate is slower (weeks to months after implantation) [1,21,27]. This

Fig. 3. Butterfly catheter is inserted into the cephalic vein for regional limb perfusion. The tourniquet is left in place for 30 minutes to allow adequate diffusion of antimicrobial to the wound in that region.

results in sustained release of antimicrobial compounds (up to 200 times that achieved through systemic administration) at the site of infection [1,27]. The antibiotic incorporated into the PMMA can be chosen based on the results of culture and sensitivity testing of the organism; however, it must be bactericidal, water soluble, and heat stable. Historically, powdered formulas were reported to be superior to liquid formulations; however, a more recent study has found that liquid antibiotic preparations are efficacious in PMMA [28]. Antibiotics that are most commonly used include gentamicin, amikacin, cefazolin, and tobramycin [1,21,27,29]. Typically, the concentration of antibiotic added to PMMA should approximate 5% of the weight of the PMMA (ie, amikacin, 0.5 g, for PMMA, 10 g) [21]. Because of their high concentration and prolonged release of antibiotics, antibiotic-impregnated PMMA beads may be a beneficial therapy in the treatment of infected synovial wounds. Long-term maintenance (9 days) of gentamicin-impregnated PMMA beads in the tarsocrural joint produced synovitis and superficial cartilage erosions [30]. Antibiotic-impregnated PMMA beads have mainly been advocated for use in orthopedic implant infections, long bone fractures, osteomyelitis, and soft tissue wounds. In the future, other biomaterials may be available that combine suitable elution characteristics in biodegradable or bioinert forms.

Synovial lavage and drainage

Physical removal of bacteria, inflammatory products, devitalized tissue, and debris is as important, if not more so, than antimicrobial therapy [3]. There are several techniques currently used to establish drainage and lavage of the synovial cavity. The aim of synovial lavage and drainage is to eliminate infection, and thus prevent damage to articular cartilage, and to reduce the formation of fibrous adhesions within synovial sheaths. Synovial lavage with a balanced polyionic electrolyte solution, combined with systemic and local antimicrobial therapy, produces the greatest chance for elimination of bacteria, resolution of infection, and return to soundness. Techniques most commonly used include arthroscopy or endoscopy, through-and-through lavage, and open drainage (arthrotomy). The technique chosen is directly related to the severity, duration, and location of the infection.

Arthroscopy or endoscopy

Endoscopic lavage and debridement is the preferred approach in all horses that have wounds with synovial involvement, especially in wounds greater than 24 hours old [1,31]. Arthroscopy, tenoscopy, and bursoscopy offer several advantages over other lavage techniques, including visibility of articular cartilage and related structures; guided removal of fibrin, debris, and osteomyelitic bone; and partial or complete synovectomy in chronic infections [32]. For these reasons, this technique has widely replaced through-and-through needle lavage in severe and chronic synovial infections. Endoscopic debridement and lavage has been shown to improve the prognosis for survival and to prevent loss of use in horses with contaminated and infected joints [3,31]. In a recent study in which endoscopy was used in conjunction with systemic and antimicrobial therapy to treat 70 horses with infected joints, 29 horses with infected tendon sheaths, 10 horses with infected bursae, and 12 horses with multiple infected synovial structures, 90% of these horses survived and 81% returned to their previous level of work [31].

Through-and-through lavage

Acute synovial injuries that are not significantly contaminated are appropriate candidates for through-and-through lavage. This technique is an inexpensive way of providing thorough lavage of synovial cavities. It is technically simpler than endoscopic surgery and can be performed multiple times in the standing sedated horse. Through-and-through lavage is performed by placing multiple large-bore needles (usually 14 gauge) or arthroscopic cannulas into the synovial space and infusing large quantities of fluid through the synovial space (Fig. 4). In one study of 15 horses that were presented within 2 days after an open joint injury, the mean number of joint lavages was 3.3 and the patient recovery rate was 87% [9]. In

Fig. 4. This horse sustained a traumatic coronary band laceration communicating with the distal interphalangeal joint. An intra-articular 18-gauge needle has been placed, and through-and-through lavage of the coffin joint is being performed. The fluid is exiting readily from the wound.

more chronic cases of synovial injury, the efficacy of through-and-through lavage is lessened by the accumulation of fibrin, which obstructs flow through the needles. As discussed previously, in chronic synovial sepsis, endoscopic lavage is preferred because it allows removal of inflammatory debris and evaluation of the synovial structures.

Arthrotomy or ventral drainage

In chronic cases or cases that are refractory to multiple joint lavage or endoscopic debridement and lavage, open arthrotomy incisions may be beneficial to allow continuous egress of fluid and decompression of the synovial space. This is usually performed after endoscopic debridement and lavage, in which an incision is created at the ventral-most aspect of the synovial cavity to allow continued drainage of synovial fluid. This technique, combined with aggressive antibiotic therapy and joint lavage, was successful in resolving joint infection in 25 of 26 horses [13]. In this study, the arthrotomy incision needed to be debrided and closed in 9 horses, and no horses experienced desiccation of the articular cartilage or secondary infection of the joint by environmental bacteria [13].

Prognosis

The prognosis for horses that sustain traumatic injuries to synovial structures is influenced by the specific structure involved, duration of the infection before treatment, and presence of osseous or tendinous lesions

[1,31,33]. Multiple retrospective studies evaluating horses with traumatic synovial injuries have provided information on prognosis.

Septic arthritis

In one study evaluating open joint injuries in horses, 54% of horses treated survived long term [34]. Of 58 horses included in the study, 36 were euthanized for various reasons relating to poor prognosis, thus leaving 21 horses for which treatment was continued [34]. In the treated horses, the best outcomes and lowest infection rates were observed in horses that were treated by administration of antibiotics and surgical lavage and debridement within 24 hours of injury. In a similar retrospective study that included 192 horses affected with septic arthritis or tenosynovitis, there was an 85% success rate in adult horses that were treated aggressively for septic arthritis [14].

Septic tenosynovitis

The most common tendon sheath involved in synovial injuries is the digital flexor tendon sheath. Other tendon sheaths involved in lacerations include the tendon sheath of the extensor carpi radialis, the common digital extensor, and the tarsal sheath. Several retrospective studies have been performed evaluating the outcome of septic tenosynovitis in horses. In one study, 18 (78%) of 23 horses that were treated for septic tenosynovitis survived for longer than 6 months after discharge, with 10 horses (56%) returning to their previous level of performance [35]. Although there was no statistical difference between medical and surgical treatment, the authors strongly recommend treating all cases of septic tenosynovitis surgically for optimal results. In a more recent study, Frees and colleagues [36] reported that 18 (90%) of 20 horses survived and 14 (70%) returned to athletic soundness after tenoscopic treatment of contaminated and infected digital flexor tendon sheaths [32].

Septic bursae

A recent retrospective study evaluating septic calcaneal bursitis in horses reported a 67% survival rate, with 81% of those horses returning to full athletic performance. In this study, involvement of the tuber calcanei carried a guarded prognosis, with only 44% of horses in which this structure was involved surviving [33]. In a study of 16 horses sustaining penetrating wounds to the navicular bursa that were treated with endoscopy of the navicular bursa, 10 horses returned to their previous level of performance [37]. Endoscopic lavage and debridement is currently the treatment of choice for septic navicular bursitis. It allows the removal of fibrin and foreign material and the debridement of lesions on the palmar or plantar surface of the navicular bone and the deep digital flexor tendon. Endoscopic surgery has a lower morbidity rate than the streetnail procedure and improves the prognosis for horses with septic navicular bursitis [37].

Early studies of horses with synovial injuries revealed a fair prognosis for survival and return to function. More recently, the prognosis has improved, because early recognition and aggressive treatment increase our ability to treat many horses successfully. It is the author's opinion that early endoscopic surgical treatment, combined with systemic, intrasynovial, and intravenous regional perfusion of antimicrobials, is the most appropriate treatment for infected synovial structures and provides the most optimal results for return to athletic function.

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