Wolf Creek Equine
936 Fiorenza Drive
Lothian, MD 20711
Office: (410) 741-1473
Fax: (410) 741-1813

Shock Wave Therapy for Lameness – Keeping up with Evolution

By Dr. Susan Mende, DVM, Dipl ABVP

Extra-corporeal shock wave therapy (EcSWT) has been around since the 1970s. It's earliest use was in human medicine to fracture bladder stones so they could pass without surgery. EcSWT has since become a therapeutic tool in human and veterinary medicine. Shockwaves are routinely used in Europe to treat common orthopedic conditions in humans including plantar calcaneal spurs (heel spurs), epicondylopathic humeri radialis (tennis elbow), epicondylitis humeri ulnaris (golfer's elbow), calcifying tendinitis of the shoulder, and non-union fractures (Haupt 1997). Shockwave therapy is currently being evaluated by the Food and Drug Administration for similar use in the United States. The first use of EcSWT in the horse was reported in the late 1990s for treating proximal suspensory ligament desmitis and osteoarthritis of the hock. The development of this modality in human and veterinary medicine in the past 10 years has resulted in a fairly dynamic knowledge base. During the past decade there have been proclamations of wonder and disgusted claims of quackery regarding this form of treatment. Fortunately, the reality lies somewhere in between.

With the increasing popularity of EcSWT, scientists have evaluated mechanisms of action and clinical efficacy and safety for use on equine bone and soft tissue. The effects of EcSWT are apparent at gross anatomic and molecular levels. Recent studies revealed that EcSWT decrease inflammation, hasten healing time, enhance neo-vascularization (blood vessel formation) and cellular proliferation, improve fiber alignment in tendon repair, increase cellular bone morphogenic protein (BMP) production, leading to faster bone healing, and recruit stem cells to injured tissues. Scientists also showed it alleviates pain from degenerative diseases. How these energy waves render these effects is still not fully understood. The following, however, is some of what is known.

What are shockwaves exactly and what effects do they have in tissues? Extra-corporeal shock waves are pressure waves generated outside the body (extracorporeal) and focused at a specific site within the body. Shock waves are characterized by high positive pressure (>80 MPa) followed by negative pressures (5-10 MPa). They have a rapid rise time of 30-120 nanoseconds and a short 5 millisecond pulse duration (Sturtevant 1996). They are different from ultrasound waves that are lower frequency, have minimal tissue absorption and no thermal effects. The pressure waves of the shock wave travel through fluid and soft tissue and their effects occur at sites where there is a change in tissue density (impedence), such as the bone-soft tissue interface.

Shock wave energy has both direct and indirect effects once within tissues. The direct effect of shock waves is mediated at the border zone between two tissues with different densities (called acoustic impedances in physics). Shock waves are deflected at the border zones of tissues with different acoustic impedance by reflection or refraction of the wave. This results in release of kinetic energy at the junction, which can cause tissue alterations. For example, a kidney stone can be cracked by a certain amount of shock wave energy, whereas in bone, the same amount of shock wave energy does not result in fragmentation. The release of kinetic energy at interfaces of different acoustic impedances is crucial in planning EcSWT.

The indirect effects of shock waves are mediated by cavitation. Cavitation is defined as the appearance of bubbles in a fluid. At the beginning of the shock wave, water molecules separate and vacuum bubbles form. Vapor from the surrounding fluid is collected within the bubbles, causing them to expand more than 10-times the original bubble volume. At the end of the negative pressure phase, the return to atmospheric pressure causes the bubbles to collapse, considered an implosion. In addition to pressure pulses that result from the implosion, water jets arise. These water jets could be destructive if excessive or uncontrolled. Focusing the shock wave's energy is an important parameter for medical applications. In addition to the mechanical effects of cavitation, there are also cellular effects. Shock waves can increase cellular permeability, stimulate cellular division and stimulate cytokine production by cells. Recent studies have shown that shock waves induce neo-vascularization at the tendon-bone junction, which in turn relieves pain and improves tissue regeneration and repair (Kirsh 2004).

How are shockwaves generated and how do the machines differ? Over the last 10 years, shockwave equipment has evolved quickly. The original dry lithotripters were large with solid articulating arms and complex aiming devices. The adaptation of shockwaves to equine therapy has necessitated equipment with more flexibility and portability. Most equine applications do not require the fluoroscopic and ultrasonographic aiming devices that were included in the original human equipment. The equipment used in the veterinary market is now essentially the same as that used in the human field and a number of machines are now available. Electrohydraulic (VersaTron), electromagnetic (Storz), and piezoelectric (PiezoVet) generators are used to create shock waves for medical application (Sturtevant 1996). These are manufactured as different types/brands of shockwave machines. The piezoelectric system utilizes a crystalline material that, when stimulated with high voltage electricity, can expand or contract to initiate a pressure wave in the surrounding fluid. The electromagnetic mechanism has coils that create opposing magnetic fields when an electric current is applied to them causing a submerged membrane to move and starting a pressure wave within the fluid. The electrohydraulic method uses a high voltage spark gap. The spark generates a plasma bubble that compresses the liquid, initiating the pressure wave. Each mechanism creates a characteristic wave form and energy density. To prevent reflection of the shock, the shock wave is generated in a fluid medium (water offset) and coupled to the skin with a fluid medium (gel).

Machines are categorized as generating focal or radial energy. Although these two waveforms are quite different, they continue to be confused and incorrectly grouped together (Cleveland 2007). An important interrelation exists between the degree of focusing of a shock wave device and the physical properties of the shock waves themselves. **Focal machines** are larger and more expensive than radial shock wave machines, and because of this the first machines used in equine practice and some of the initial research involved **radial machines**. While both types of machines create pressure gradient waves, the focal machines create waves that focus on a specific point. Shock wave devices that concentrate acoustic energy into small focal areas increase the desired effects within the target area while minimizing the potential undesired side effects in surrounding tissue. Focal machines deliver superior shock wave energy.

Radial pressure wave generators are still available; however, they do not produce a true extracorporeal shock wave as defined by the industry. They use mechanical concussion to generate a pressure wave with a slower rise time. The kinetic energy of a projectile driven by compressed air is transmitted by an elastic concussion to the probe and no focusing mechanism exists. The maximal energy is delivered to the skin surface rather than deeper tissues. Basic physics suggest that as the distance from a radial pressure wave machine increases, the energy of the wave drops dramatically. In other words, radial pressure waves are logically less effective in treatment of deeper tissues. However, because the majority of orthopedic injuries in the horse are relatively close to the skin surface (distal limb injuries), many believe that radial pressure waves deliver sufficient energy for superficial injuries (called radial shock wave therapy, RSWT). They are less precise but also less harmful.

Can it harm tissues? Like many things, focal shockwave therapy has to be used precisely and at the correct dosage to achieve the desired effect. Studies that look at dose effects of shock waves consistently indicate a minimum energy level that must be attained to stimulate cells and a maximum level, which when exceeded leads to cellular damage.

Focused shock waves produce measurable cavitation formation compared to radial pressure waves (Cleveland 2002). These bubbles accumulate large amounts of energy that is released when the bubble implodes, resulting in high-energy water jets and high temperatures. It is this effect that may damage the surfaces adjacent to the damaged tissues (McClure 2004). It is important that the operators of focal shock wave machines treat the ***maximally injured zone*** of the tissue, avoiding the application of shocks over healthy adjacent tissue.

The ***energy level and the number of shock waves applied*** in each session are essential factors in determining the therapeutic effect of shockwave therapy. This was demonstrated in investigations showing the effects of extracorporeal shockwaves on osteoblast cells in vitro (Wang 2002) and in a study demonstrating that shockwave therapy leads to a dose-dependent enhancement of bone mass and bone strength after fracture of a femur (Wang 2004). In healing of split-thickness wounds using a standardized model in piglets, shockwaves at low-energy levels stimulated cells while high-energy shockwaves led to necrosis and scar formation (Haupt 1990).

When human cancellous bone cells in culture were treated with shock waves, there was a short-term effect of cellular death but a medium term effect of cell-stimulation that was dependent upon the number of pulses delivered. One of the first studies on the effect of shock waves on fracture healing was completed in rats. Treated bones were found to be heavier than controls, had breaking strength 30% greater than controls, and healed faster. In two soft-tissue studies, dose-related effects of shock waves were identified. Low-dose EcSWT enhanced the healing of skin wounds in pigs in both normal tissue and in tissue in which healing had been delayed by radiation treatment. High-dose EcSWT inhibited healing of wounds. At high energies, EcSWT can be cytotoxic and has been investigated as a noninvasive mechanism to destroy neoplastic cancer cells and to increase cell wall permeability, thereby increasing cytotoxic effect of chemotherapeutic medications. The energy level and the amount of pulses must be taken into account when comparing results of different studies. ***In all studies, the biologic effects of shock waves depended on the number of shock wave pulses administered***.

So it seems the type of machine, the type of energy generating the shock, the region to which the shocks are being applied, the energy setting, number of shocks, and number of treatments are all important factors in the application and use of shock wave therapy. What then are the applications to the horse, and specifically, to a horse with a lameness issue? Here are a few documented uses:

Suspensory Desmitis: Therapies for chronic insertion desmopathy of the proximal suspensory ligament in front and hind legs of horses can be frustrating. The condition has been reported most commonly in mature sport horses of 4-10 years of age. To date, treatment has consisted largely of combinations of rest and controlled exercise. Internal blistering with iodine and peanut oil (Crowe 2002), corrective shoeing (Redding 1999), intra-lesional injections of bone marrow, and tibial neurectomy or fasciotomy with neurectomy of the deep branch of the lateral plantar nerve of the hind limb also have been described. However, none of these methods consistently result in a satisfactory outcome. This condition is characterized by a high rate of recurrence and low success rates. The prognosis for hindlimb proximal suspensory disease is guarded, with only 13% of 45 horses in one study reported to return to their previous occupation at 6 months, none of which were chronic cases (Crowe 2002).

The earliest studies with RSWT were performed on chronic suspensory ligament injuries. In one study using RSWT, 73% of horses with longstanding lameness improved and a majority showed reduction of pain (Boening 2000). A later study found 41% of horses with chronic hind limb suspensory desmitis improved on ultrasound and returned to their previous level of work after 6 months. This was substantially better than previously reported results using controlled exercise alone. RSWT was speculated to reduce the time for return to soundness and full work. Studies assessing controlled exercise alone have described a program lasting 36 weeks whereas some of the horses in this trial were sound at a trot by the second or third treatment. RSWT appeared to improve the prognosis for return to soundness.

Other studies demonstrated significantly faster healing times on experimentally-induced acute suspensory ligament injuries compared to controls, and recommends EcSWT before resorting to more invasive treatments (McClure 2002) such as surgery. In both studies the ultrasonographic measurements of the defects healed faster in the EcSWT treated group. In the study evaluating desmitis of the forelimb, there was increased production of extracellular matrix. In the study evaluating desmitis of the rear limb there were more newly formed small collagen fibrils. Initial clinical observations indicate that the lesions heal faster when EcSWT is administered at 2- 3 week intervals during the healing process. Lower energy levels are used during the acute phase and are increased in the more chronic cases (McClure 2004).

Osteoarthritis of the distal intertarsal and tarsometatarsal joint: Hock osteoarthritis (bone spavin) is a common cause of hind limb lameness in horses. Typical treatment consists of intra-articular corticosteroids/hyaluronic acids and anti-inflammatory drugs. Horses that are refractory to treatment or require frequent treatments with decreasing benefit are candidates for more aggressive treatment. Treatments that have been developed for horses that are refractory include cunean tenectomy and ankylosis by surgical and nonsurgical methods. The first published study of EcSWT in the United States was a case series of horses with bone spavin. At follow up examination 90 days after treatment, 80% of horses had improved at least one lameness grade. No horse had increased lameness following treatment and there were no serious complications associated with the procedure.

Horses with osteophyte formation on the dorsal or dorsomedial aspect of the tarsometatarsal joint seemed to improve most consistently. Follow-up radiographs taken at 90 days post-treatment showed no consistent changes when compared to pre-treatment radiographs. There did not appear to be an accelerated ankylosis (fusion) of the joints. A similar finding of decreased pain with few radiographic changes has been identified in humans with heel spurs (Buch 1998). Similarly, human patients that became pain free remained so.

A potential explanation for decreased lameness in these horses is strengthening of the subchondral bone. EcSWT has been demonstrated to increase osteoblastic activity resulting in thickening of cortical bone (Haupt 1997). Subchondral bone maintains joint shape and contributes to shock absorption which acts to spare the cartilage from damage (Palmer 1996). The results of this study indicated that EcSWT should be considered as a viable noninvasive mechanism to treat bone spavin in the horse.

Digital Flexor Tendonitis: Superficial and deep digital flexor tendinitis respond to EcSWT by decreasing the cross-sectional area of the lesion faster than traditional conservative methods. Several recent studies evaluated the effect of shock waves on tendons and ligaments and found evidence that shock waves induce neo-vascularization at the tendon-bone junction, which may decrease pain and improve tissue regeneration and repair. Histologic examination of treated tendons showed the tenocytes were more mature, indicating the healing process was progressing at a faster rate. The treated tendons also had more parallel collagen fibers and increased tensile strength compared with the control group. It is thought the pressure waves might help physically break down or move a hematoma or fluid from the damaged tissue to allow the fibroblasts to more rapidly fill the defect. The effect of EcSWT on disease recurrence and future ligament strength has not been evaluated.

Dorsal periostitis/Bucked shins: Dorsal metacarpal disease is a common fatigue injury of bone in young performance horses, estimated to affect up to 70% of Thoroughbred racehorses in training. Dorsal metacarpal disease includes a wide variety of pathologic changes in the third metacarpal bone, including periosteal new bone formation, focal lysis within the dorsal cortex, and fracture. Treatment may include controlled exercise, non-steroidal anti-inflammatory drug medication, periosteal scraping, blistering, pin firing, fenestration, or internal fixation. “Bucked shins” are the result of bone remodeling in response to loading. In a research study using horses that were unresponsive to conventional therapy, EcSWT was 90% successful (Palmer 2002). Horses that develop pain and periosteal remodeling can be maintained in training by utilizing EcSWT at 1-2 week intervals for 3 treatments.

Navicular syndrome: In one study, 70% of the treated equine limbs improved at least one grade of lameness. The decreased lameness in these horses is encouraging because many of these horses had been chronically lame and most had been unresponsive to previous conventional treatments. A similar finding of decreased pain with few radiographic changes has been identified in humans with heel spurs (Kusnierczak, 2000). Similar to this study, human patients that became pain-free remained so. Horses that respond remain improved for one year after treatment; however, recurrence at some point could occur.

A proposed mechanism for the alleviation of pain and lameness is that neo-vascularization decreases the avascular necrosis. EcSWT has been shown to stimulate neo-vascularization of the bone-tendon junction that could occur in the navicular bone and impar and collateral sesamoidean ligaments (Wang 2000). Studies of navicular bone blood supply indicate that ischemia and increased intra-osseous pressure contribute to the changes seen with navicular syndrome (Pleasant 1993). Additionally, bone remodeling stimulated by EcSWT may allow healing of the degenerative changes associated with navicular syndrome.

Wounds and soft tissue disorders: The use of shockwave therapy for treating soft tissue disorders has increased in human medicine. In one study, the use of shockwave therapy to experimentally create skin wounds in pigs resulted in improved rates of epithelialization (Haupt 1990). In another study in rats, the use of shockwave therapy resulted in a significant decrease in necrosis of epigastric skin flaps (Meier 2005). The results of initial clinical studies in humans with diabetic ulcers are promising (Saggini 2008) as are the results of a study involving skin wounds on the distal limbs of horses, in which several parameters associated with wound healing were evaluated (McClure 2007). In the horse, the time for wound healing was shorter following shockwave therapy (Morgan 2009). However differences in wound area, wound epithelialization, and wound contracture were only identified on a few occasions during healing.

Inflammation: Veterinarians have noticed a rapid decrease in the clinical signs of inflammation in some horses after shock-wave therapy. These findings are particularly interesting considering that many people would expect shockwave therapy to result in increased inflammation. These findings also seem to dispel the opinion that shockwave therapy is simply an ‘internal blister.’

In a study comparing horses treated with a common non-steroidal anti-inflammatory drug, EcSWT performed better, promoting improvement in clinical lameness and increased synovial fluid total protein and increased amount of glucosaminoglycan release into the bloodstream. EcSWT reduced the clinical signs of pain measured by lameness evaluation 42 days after final treatment. These results suggest that EcSWT is an effective method of reducing clinical lameness and synovitis, but does not improve gross progression of arthritis significantly. The concurrent use of chondro-protective medications may still be wise and recommended on a case-by-case basis.

More recently, researchers evaluated EcSWT antibacterial effects. They found that as they increased the number of shock waves, the number of viable bacterial cells decreased because the cells protective barriers weakened. EcSWT could become a novel treatment for certain bacterial infections on the skin or even of the bone and soft tissue structures within the body.

Stress fractures: The first application of shockwave therapy for musculoskeletal disorders in humans and horses was to treat diseases that affect bone. Subsequently, large retrospective studies in humans have resulted in refinement of the treatment protocols to yield the desired response (Shaden 2008). However, in horses, shockwave therapy for bone disorders has not been pursued as aggressively as it has in humans. This may be related to differences in case management in equine patients. One of the major concerns in dealing with stress fractures in racehorses is the decision on when it is safe to return the horse to work. The response of incomplete fractures, such as dorsal cortical fractures, to EcSWT is moderate at best.

In studies involving the application of shock waves on bones, it was determined that relatively low energy levels do not stimulate bone formation whereas those that use high energy levels result in bone formation (Delius 1998). This study supports the findings of a previous study that the primary mechanism for stimulation of osteogenesis is not the induction of micro-fractures (Delius 1995).

Does a shockwave treatment hurt? Yes. Human patients subjected to shockwave treatments describe a pain similar to hitting the funny bone, then a numbing effect as more shock waves are applied. Most patients (human, equine, canine, etc.) require sedation to tolerate the discomfort associated with a shockwave treatment.

A post-treatment analgesic effect has been reported in humans following EcSWT. Several hypotheses exist regarding the mechanism of this effect, including destruction of nerves, nerve receptors, and central control of sensory input. None of these theories is truly supported by research. EcSWT is known to raise the threshold potential of nerve membranes. Some in vitro data are available concerning the direct effects of shock waves when used to repetitively generate action potentials from the nerve. The conclusion was that shock waves do not directly affect nerves, but the nerves are affected through the interaction with small gas bubbles.

The possibility exists that after therapy a horse may be at risk of incurring a significant injury if worked without full sensory input. A number of anecdotal and published reports in the horse have had conflicting results as to the presence and duration of analgesia (McClure 2005). Analgesia after EcSWT was documented to last from 8-48 hours after treatment in the horse using a force-plate model. After 48 hours there was no measurable difference. It is generally accepted that horses should have limited exercise for a minimum of two days after shockwave therapy to avoid potential injury caused by lack of pain perception. Based on this evidence, racing jurisdictions in the United States and the International Equestrian Federation have adopted regulations that require a 5 to 7 day waiting period between a treatment and a performance event.

Are there potential complications? In humans and small animals, petechiation (blotching) of the skin at the treatment site has been reported. This is not seen in the horse. Treatment protocols vary and veterinarians use trodes (or probes) depending on the depth of the injury. In general, a single treatment consists of 500-2000 pulses to the area every 1-4 weeks, for an average of three total treatments (or as needed based on the problem). As emphasized earlier, excessive energy and/or pulse numbers have the potential to cause tissue necrosis. It is therefore important to keep in mind that more is not necessarily better and the treatment region should be very specific.

Gas-tissue interfaces should be avoided (lung and intestine), since energy release would be unpredictable. Major blood vessels should not be in the focal zone. The effect on nerve tissue has not been identified fully, so important, large nerves should also be avoided. Active physes (growth plates) should be avoided because studies have demonstrated that premature closure of the physis in laboratory animals is possible after EcSWT.

So . . . proclamations of wonder or disgusted claims of quackery? Maybe now you can decide for yourself.

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