Two Emerging Technologies for Achilles Tendinopathy and Plantar Fasciopathy

Paul Langer, DPM, ABPM, FAAPSM*

KEYWORDS

• Achilles tendinopathy • Plantar fasciitis • Extracorporeal shock wave therapy
• Percutaneous tenotomy • Percutaneous fasciotomy

KEY POINTS

- Some overuse musculoskeletal injuries can be resistant to standard therapies. Alternative therapies may be considered earlier in the continuum of care and before surgical options are pursued.
- Extracorporeal shock wave therapy is becoming a more commonly used treatment modality in sports medicine and provides a noninvasive treatment option for tendon and fascia injuries.
- Ultrasound-guided percutaneous tenotomy/fasciotomy is a newer, minimally invasive technology that provides additional treatment options that may be considered before more invasive surgical interventions.

By some estimates 10% to 25% of individuals affected by Achilles tendinopathy and plantar fasciitis fail conservative treatment.[1–3] For those individuals who fail nonoperative modalities, operative intervention is often the next option. Recently, 2 other treatment options have shown potential as viable options for treatment of these conditions before surgery.

EXTRACORPOREAL SHOCK WAVE THERAPY

The use of acoustic energy in the form of unique sets of "high-energy" acoustic pressure waves or sound waves to treat musculoskeletal injuries has been around for approximately 30 years and the volume of research on effect, potential benefit, and

Disclosures: None.
Department of Family Practice, University of Minnesota Medical School, Minneapolis, Minnesota
* Corresponding author.
E-mail address: paullanger@tcomn.com

Clin Podiatr Med Surg ■ (2015) ■–■
http://dx.doi.org/10.1016/j.cpm.2014.11.002 **podiatric.theclinics.com**
0891-8422/15/$ – see front matter

mechanism of action continues to grow. Shock wave therapy (SWT) is a relatively new technology that has become increasingly popular as a treatment for musculoskeletal conditions, in part because it is noninvasive and clinically and economically effective. It also allows athletes to remain active during the treatment process. SWT is approved and/or cleared by the US Food and Drug Administration for treatment of musculoskeletal pain, plantar fasciitis, and lateral epicondylitis, and has been used for other off-label indications, including tendonopathies and other musculoskeletal conditions.[4] Overall, research is mixed in terms of the effectiveness of SWT.[4–7] A significant limitation to drawing definitive conclusions about the effectiveness of SWT is the variability in study design and methods, which makes it difficult to pools results. More research needs to be done to better elucidate effectiveness, optimal methodologies, adjunctive treatments, and posttreatment protocols.

Background and Technology

In the 1980s, shock waves began to be used to treat kidney stones.[8] The research on animals that preceded this clinical use suggested that there were also potentially beneficial effects on musculoskeletal structures. Subsequent research on the effects on bone, cartilage, muscle, tendon and ligaments eventually led to other clinical applications and SWT has become increasingly popular as a treatment modality. SWT is often called extracorporeal SWT.

Therapeutic shock waves are unique sets of acoustic pressure waves directed through a medium. They are typically classified as either focused or unfocused. Focused waves were used more commonly in the earlier days of clinical application, but recently unfocussed (or, as they are more commonly called, “radial”) pressure waves are used with increasing frequency. Radial pressure waves are used increasingly more often because they can be applied without local anesthesia and have the potential to be less injurious. In addition, improved technology makes the machines less costly to own and operate, and more convenient to use in clinical settings.[3,9] Multiple investigators have concluded that no evidence clearly favors either focused or radial shock wave therapy.[4,10] Other authors have shown that extracorporeal SWT delivered without local anesthesia was more effective compared with delivery under local anesthesia.[11,12] Because radial SWT (RSWT) is being used more commonly in clinical settings and can be delivered without local anesthesia, it is the focus of this review.

Ogden and colleagues[13] described therapeutic shock wave as a “controlled explosion” that will be reflected, refracted, transmitted, and dissipated as it travels through tissue. As it travels, a pressure phase is followed by a low-pressure or tensile phase, and then cavitation follows. Any change in tissue type presents a boundary, and it is at these boundaries or tissue interfaces where the biological effects of cavitation occur.[14,15] Structures like cartilage and bone reflect the energy of the wave, whereas structures with high collagen content, such as tendon, ligament, and joint capsule, tend to absorb the wave.[16,17]

The shock wave can be generated in a number of different ways, but the most commonly used and clinically validated method for RSWT is pneumatic. The energy content of the pressure wave can be varied depending on the selected settings and equipment; the propagation of the wave will vary with tissue type. With radial acoustic pressure waves, the skin is subjected to the greatest concentration of energy; as the wave travels through other tissues, a steep drop off of energy occurs. Structures that are close to the skin surface are especially impacted by SWT (**Fig. 1**).[4]

The acoustic pressure wave can be manipulated in a number of ways, one of which is by varying the amount of energy per unit area per pulse. This is known as the energy

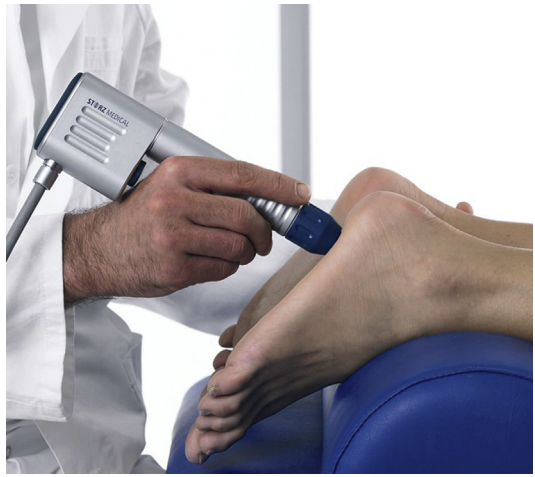

Fig. 1. Radial wave therapy machine with hand piece positioned to treat plantar fasciitis. (*Courtesy of* CuraMedix LLC, Lincoln, RI; with permission.)

flux density (EFD) and is measured in mJ/mm^2. The safe, effective range of EFD is approximately between 0.14 and 0.5 mJ/mm^2.[18–20] The pulses per second can be adjusted as well and are measured in Hertz (Hz). The total number of shocks delivered per treatment session typically varies from 500 to 3000, depending on the tissue being treated, depth of tissue penetration requirements, clinical judgment, research, and manufacturer recommendations. Finally, the number of treatments and interval between treatments has not been standardized, but 3 to 5 weekly treatments are a common protocol seen for Achilles tendinopathy and plantar fasciitis.

There have not been many studies or consistent recommendations on the proper "dose" of shock waves for specific pathologies. This is an area that clearly needs more study, not only to improve understanding of the technology, but also to better track outcomes. Tam and associates[21] proposed calculating a total energy dose by multiplying the EFD by the number of shocks to quantify treatment dose and provide objective data for outcomes studies.

Rompe[22] stated that level I therapeutic studies have provided evidence for plantar fasciitis treatment benefits utilizing the following protocol:

1. Application of 1500 to 2000 shocks at an EFD 0.08 to 0.15 mJ/mm^2;
2. Application to site of maximal discomfort via patient guidance;
3. No local anesthesia;
4. Three to 4 applications spaced at 1 week between applications; and
5. At least 3 months of follow-up after the last treatment.

Biologic Effects

Research is starting to elucidate some of the mechanisms for how shock waves promote tissue repair. There have been immediate, short-term, and extended effects reported, but the mechanism for these effects remain poorly understood. The primary mechanisms of healing response most often cited in the literature are ones of an initial inflammatory response followed by neovascularization. Saxena and colleagues[23] described RSWT as creating "a controlled, microtrauma to local affected tissue to stimulate a healing response and micro-vascularization." The initial microtrauma

causes a transient inflammatory response that subsides in approximately 1 week and is followed by a remodeling phase, which occurs at around 3 weeks after treatment.[13,14] Some subjects report immediate but often temporary analgesia after treatment. These analgesic effects may be derived from hyperstimulation, depletion of substance P, or other effects on pain receptors.[19,24,25]

Weihs and colleagues[26] showed that SWT enhances cell proliferation in vitro and wound healing in vivo. They identified adenosine triphosphate as a trigger of a chemical cascade that then leads to a healing response via purinergic signaling and, eventually, increased collagen synthesis.[27] Neovascularization effects have been shown through angiogenesis via cellular mediators, such as vascular endothelial growth factor, as well as enhanced expression of other proangiogenic cells, including cytokines and fibroblasts.[28–31] The neovascularization effect increased in the first 8 weeks and was still present at 12 weeks in a rat tendon study reported by Takahashi and co-workers in 2003.[32] Because neovascularization and collagen synthesis are slower to occur events in healing, it is speculated that maximum benefit of RSWT may be 90 to 120 days, or later, after treatment.

Podiatric Indications

Two common conditions treated by podiatric physicians that can be refractory to conventional treatment are Achilles tendinopathy and plantar fasciopathy. Patients who have failed conventional therapies are often faced with the prospects of living with their condition, considering operative interventions, or considering newer and alternative therapies or treatments. The bulk of the literature on lower extremity conditions and RSWT is found for these 2 conditions. Potential benefits are best when combining SWT with tissue-specific stretching and strengthening exercises, as well as tissue loading changes.[5,6,33,34]

Achilles tendinopathy

Rasmussen and colleagues,[35] in a randomized, double-blinded, placebo-controlled trial in 2008 found improved function scores in subjects treated with extracorporeal SWT, stretching, and eccentric exercises versus sham treatment, stretching, and eccentric exercises at 8 and 12 weeks after treatment. However, the test subjects had no significant change in pain scores. The combination of radial shock waves and eccentric loading tended to provide faster symptom relief compared with treatment alone, but no difference in outcome was found after 1 year in a study by Rompe and associates in 2009.[6] In a review of the literature, Foldager and colleagues[4] found that, for both insertional and noninsertional Achilles tendinopathy, shock wave therapy showed a significant benefit. However, Magnussen and co-workers,[36] in a systematic review, concluded that more research needed to be done before drawing conclusions. Saxena and colleagues,[37] in a prospective study on 74 tendons, showed reduced pain and improved function in 78% of subjects 1 year after treatment with RSWT. They noted no adverse events and athletic individuals were able to continue their activity.

Plantar fasciitis

Sems and associates[38] review from 2006 concluded that there was a “preponderance” of the evidence to support the use of shock wave for refractory plantar fasciitis and noted that directing the shock wave at the calcaneal spur or maximal area of pain provided the most favorable results.

Other studies have shown benefits of shock wave in treating plantar fasciitis as well. Gerdesmeyer and colleagues,[39] in a randomized, double-blinded study with 115 patients, reported significantly reduced pain scores compared with untreated control

group. They treated in 3 sessions of 2000 shocks each spaced weekly, at an EFD of 0.16 mJ/mm^2, and found significant pain reduction at 12 weeks compared with untreated control group. Ibrahim and colleagues[40] in 2010 achieved reduced pain scores on a visual analog scale in 50 patients treated with 2 treatments of 2000 pulses spaced 1 week apart versus a placebo treatment group.

Two small studies failed to show significant benefit of SWT. Mark's study of 25 subjects failed to show a benefit of 3 treatments spaced 3 days apart using 500 to 2000 shocks.[41] Greve and colleagues[42] found benefit of SWT, but it was not superior to plantar fascia stretching exercises in a study with 36 subjects. Hsu and associates[43] found reduced pain and improved gait parameters in 12 patients after 3 weekly treatments of SWT.

Adverse Effects

The most common side effects reported are minor, such as petechial bleeding, swelling, and discomfort during treatment.[4,9,12,22,23,34] A case report described an Achilles tendon rupture after a single shock wave treatment. However, the patient had also undergone multiple other treatments including calcaneal exostectomy and cortisone injections.[44]

Summary

Despite mixed results in the literature, RSWT may be a viable treatment option after other treatments have failed and before considering surgical intervention for Achilles tendinopathy and plantar fasciitis. The literature is more conclusive in the benefits for plantar fasciitis. Although more research needs to be done, shock wave therapy does show potential to be a safe and effective adjunct treatment option for refractory conditions.

PERCUTANEOUS ULTRASONIC FASCIOTOMY FOR PLANTAR FASCIOSIS

Recently, percutaneous ultrasonic tenotomy and fasciotomy have become available to treat chronic tendon disease and plantar fasciosis.[45–48] This minimally invasive technique is based on the physical principles of phacoemulsification, whereby ultrasonic energy is utilized to precisely emulsify and remove tissue in the vicinity of a working tip that oscillates at high frequencies.[45,49] Although phacoemulsification was originally popularized to remove cataracts, the technology has been further developed to treat tendon and fascial disease percutaneously using a hand piece and portable console (Tenex Health, Inc., Lake Forrest, CA, USA).[45,49]

Technology and Instruments

The hand piece contains an 18-gauge, inner, stainless steel tube connected to a series of piezoelectric crystals electronically driven at high frequencies to produce low-amplitude oscillations in the working tip (**Fig. 2**). The central lumen of this tube is attached to a suction system within the console that aspirates lavage fluid and tissue debris into a collection bag. The inner tube is surrounded by an outer plastic tube that is slightly recessed, thus exposing only a small portion of the working tip. Pressurized lavage fluid emerges between the outer plastic tube and the stainless steel inner tube, cooling the working tip and providing fluid for lavage and debris removal. The working tip is controlled by a foot pedal that activates the ultrasonic energy. When activated, the working tip oscillates while pressurized fluid emerges into the working field and is aspirated through the central lumen of the inner tube. Tissue within 1 mm of the working tip is emulsified and aspirated via the process of cavitation.

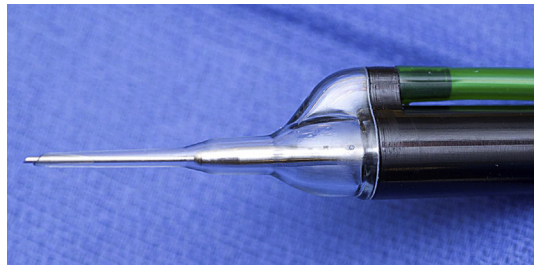

Fig. 2. The TX1 working tip, demonstrating the distal end of the hand piece and the working tip. Note the plastic outer tube, through which the 18-gauge, stainless steel inner tube protrudes slightly. When the piezoelectric crystals in the hand piece are activated by the foot pedal, the inner tube vibrates with high-frequency, low-amplitude oscillations, emulsifying tissue within 1 mm of the tip. Pressurized fluid flows into the working area between the plastic outer tube and stainless steel inner tube, and is removed via a vacuum suction through the lumen of the inner stainless steel tube. The fluid inflow–outflow is continuous during working tip activating, cooling the tip and removing emulsified tissue, which is collected in a bag attached to the TX1 desktop console (not shown).

Percutaneous ultrasonic fasciotomy can be used to treat chronic plantar fasciosis under ultrasound guidance.[50] The most common indication is chronic, refractory plantar fasciosis unresponsive to standard treatments and accompanied by structural changes as identified on ultrasonography or MRI. The exact mechanism of action has not been determined precisely, but percutaneous ultrasonic fasciotomy likely works primarily by removing the pathologic tissue associated with pain and consequently facilitating a healing response.[45] Koh and colleagues[48] reported improvements in the ultrasonographic appearance of the common extensor tendon after successful treatment of lateral elbow tendinopathy with percutaneous ultrasonic tenotomy. Current investigations are ongoing to determine the histologic changes over time after percutaneous ultrasonic tenotomy.

Treating Plantar Fasciopathy

To perform percutaneous ultrasonic fasciotomy, the plantar fascia is first examined using standard ultrasonographic techniques.[48,50] Plantar fasciosis manifests as diffuse or focal thickening, heterogeneity, and hypoechogenicity (ie, dark) of the plantar fascia, typically affecting the central cord (**Fig. 3**).[48,51] In some cases, these ultrasonographic findings may be accompanied by focal, hypoechoic–anechoic regions representing partial thickness tearing, Doppler flow consistent with neovascularization, and/or cortical irregularities, including plantar calcaneal spurs.[49] The affected region of the plantar fascia is identified and the skin marked with an indelible ink marker.

The patient is typically placed prone or in a lateral decubitus position for a medial to lateral approach, short axis to the plantar fascia. However, a long axis approach to the plantar fascia is possible.[48,50] The area is prepared in the usual sterile fashion and the use of appropriate draping, sterile ultrasound transducer covers and sterile ultrasound gel can ensure sterile working conditions throughout the procedure. The plantar fascia is identified in the short axis and local anesthesia is obtained using 1% lidocaine and a ultrasonographically guided, in-plane, medial to lateral approach with a 25-gauge needle or equivalent (an ultrasound-guided tibial nerve block may be performed as an alternative for anesthesia).[48,51] Approximately 4 to 8 mL of lidocaine are injected into the skin, subcutaneous tissue, fat pad, and superficial portions of the plantar

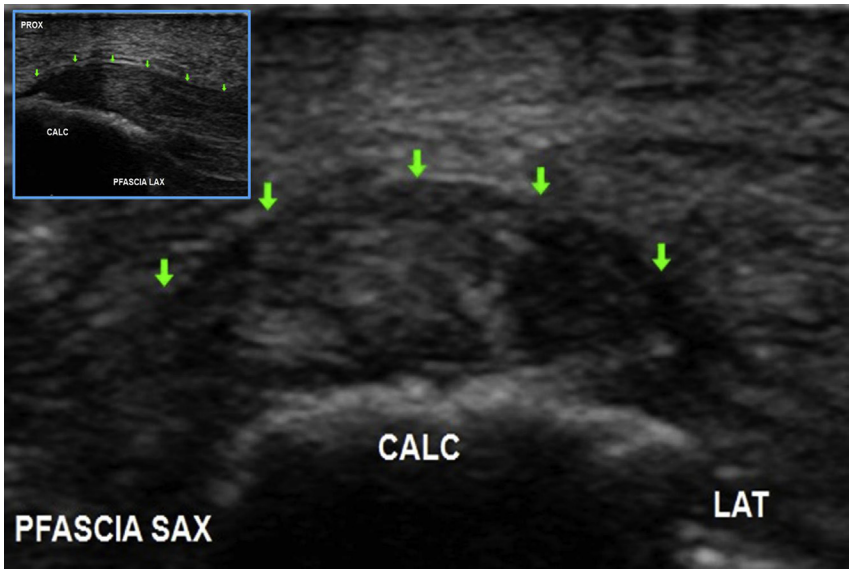

Fig. 3. Correlative short axis ultrasound view of a thickened, heterogenous, hypoechoic plantar fascia (PFASCIA) typical of chronic plantar fasciosis. *Top*, Plantar/superficial; *bottom*, dorsal/deep; *left*, medial; *right*, lateral (LAT). Green arrows identify superficial portion of plantar fascia. Inset shows correlative long axis (LAX) view, proximal to the left. CALC, calcaneus.

fascia at the anticipated point of entry. Thereafter, a small stab incision is completed (blade oriented parallel to the plantar aspect of the foot) using a #11 scalpel blade to creating a 2- to 3-mm skin incision. The blade is advanced toward the plantar fascia using direct ultrasound guidance. After this, the TX1 tip is advanced using a similar sonographically guided, in plane, medial to lateral approach, until it contacts the medial aspect of the affected portion of the plantar fascia (Fig. 4). Some users prefer to precede TX1 placement by passage of a 14-gauge needle to create a wider channel for the TX1 tip. Once the TX1 tip is placed adjacent to the plantar fascia, the working tip is activated via the foot pedal. The operator gently moves the TX1 tip into the plantar

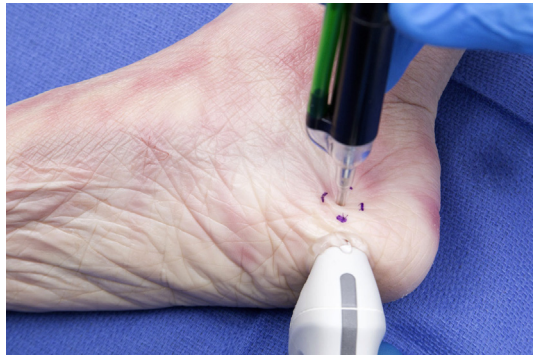

Fig. 4. After delivery of local anesthesia as described in the text, a small stab incision is created with a #11 scalpel blade to create a passage to advance the TX1 working tip to the plantar fascia under direct ultrasound guidance. *Left*, distal (toes); *right*, proximal (heel).

fascia using direct ultrasound guidance. As the tip enters the fascia, the fascia is cut via phacoemulsification and the debris and inflow fluid removed via the hand piece outflow and transferred into the collection bag on the console.[45,50] During the fasciotomy and debridement process, the operator moves the working tip in low-amplitude, back-and-forth motions while its position is monitored using orthogonal ultrasound imaging.[45–47,50] Typically, 4- to 5-second pulses of energy are used, with a total energy time of 30 seconds to 2 minutes, depending on the size of the treated region. Using ultrasound imaging, all affected areas are treated as dictated by the clinical scenario.

At the completion of treatment, the TX1 tip is removed, the wound dressed with adhesive strips, a pressure gauze bandage and sterile occlusive dressing, and postprocedural instructions are reviewed with the patient.[45,50] Edema control, icing, range of motion, and gentle stretching are recommended for all patients immediately after the procedure until the initial follow-up. Some patients may benefit from a period of modified weight bearing in a walking boot and/or crutches as dictated by the extent of treated pathology and individual clinician's preference.[50] Over-the-counter analgesic and anti-inflammatory medications can be taken as necessary; prescription-strength medications are not often required. Patients are typically seen 2 to 4 weeks after the procedure, at which time rehabilitation and return to activities is individualized based on the extent of structural pathology and patient-specific factors. Many patients may return to running 6 to 8 weeks after the procedure, although the recovery course can be highly variable.[50] Of note, as is the case for some minimally invasive procedures, many patients experience early pain relief before adequate tissue healing, placing them at risk to overstress the healing tissues early in the rehabilitation process. Patients should be counseled accordingly.

Percutaneous ultrasonic tenotomy and fasciotomy is a well-tolerated, minimally invasive outpatient procedure that seems to be both safe and effective when applied to a variety of tendons throughout the body, as well as the plantar fascia.[45–47,50] Two prospective case series including a total of 39 patients have documented satisfactory results in more than 80% of patients with chronic, refractory elbow tendinosis at 1 year after treatment.[47,48] The total energy time for patients in these series was generally less than 60 seconds, with total treatment times of approximately 15 minutes, including preparation and skin marking.[46,47] No complications were reported in either series.[46,47] With respect to the plantar fascia, the total procedure time is also typically less than 15 minutes, patients typically require no more than 10 mL of 1% lidocaine for anesthesia during the procedure, and the postprocedure recovery and rehabilitation are uncomplicated. Patel and colleagues[49] recently reported 100% satisfactory results at 2 years among 12 patients (13 feet) with greater than 12 months of refractory plantar fasciosis who were treated with percutaneous ultrasonic fasciotomy. Percutaneous ultrasonic fasciotomy seems to warrant further consideration as a definitive treatment for chronic, refractory plantar fasciosis.

ACKNOWLEDGMENTS

The author of this article would like to thank Dr. Jay Smith for his assistance in preparation of this article.

REFERENCES

1. Alfredson H, Pietilä T, Jonsson P, et al. Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. Am J Sports Med 1998;26(3):360–6.

2. Davis PF, Severud E, Baxter DE. Painful heel syndrome: results of non-operative treatment. Foot Ankle Int 1994;15(10):531–5, 4.
3. Malay DS. Plantar fasciitis and heel spur syndrome: a retrospective analysis. In: Vickers NS, editor. Reconstructive surgery of the foot and leg: update '96. Tucker (GA): Podiatry Institute Publishing; 1996. p. 39–43.
4. Foldager CB, Kearney C, Spector M. Clinical application of extracorporeal shock wave therapy in orthopedics: focused versus unfocused shock waves. Ultrasound Med Biol 2012;38(10):1673–80.
5. van der Worp H, van den Akker-Scheek I, van Schie H, et al. ESWT for tendinopathy: technology and clinical implications. Knee Surg Sports Traumatol Arthrosc 2013;21(6):1451–8.
6. Rompe JD, Furia J, Maffulli N. Eccentric loading versus eccentric loading plus shock-wave treatment for midportion Achilles tendinopathy: a randomized controlled trial. Am J Sports Med 2009;37:463–70.
7. Chung B, Wiley JP. Extracorporeal shockwave therapy—a review. Sports Med 2002;32:851–65.
8. Chaussy C, Schuller J, Schmiedt E, et al. Extracorporeal shock-wave lithotripsy (ESWL) for treatment of urolithiasis. Urology 1984;23:59–66.
9. Watson T. Shock wave therapy. Available at: www.electrotherapy.org. Accessed September 12, 2014.
10. van der Worp H, Zwerver J, Hamstra M, et al. No difference in effectiveness between focused and radial shockwave therapy for treating patellar tendinopathy: a randomized controlled trial. Knee Surg Sports Traumatol Arthrosc 2014;22(9):2026–32.
11. Labek G, Auersperg V, Ziernhold M, et al. Influence of local anesthesia and energy level on the clinical outcome of extracorporeal shock wave-treatment of chronic plantar fasciitis—a prospective randomized clinical trial. Z Orthop Ihre Grenzgeb 2005;143:240–6.
12. Rompe JD, Meurer A, Nafe B, et al. Repetitive low-energy shock wave application without local anesthesia is more efficient than repetitive low-energy shock wave application with local anesthesia in the treatment of chronic plantar fasciitis. J Orthop Res 2005;23:931–41.
13. Ogden JA, Alvarez RG, Levitt R, et al. Shock wave therapy (orthotripsy (R)) in musculoskeletal disorders. Clin Orthop Relat Res 2001;(387):22–40.
14. Ogden JA, Toth-Kischkat A, Schultheiss R. Principles of shock wave therapy. Clin Orthop Relat Res 2001;(387):8–17.
15. Kearney CJ, Lee JY, Padera RF, et al. Extracorporeal shock wave-induced proliferation of periosteal cells. J Orthop Res 2011;29:1536–43.
16. Watson T. Ultrasound in contemporary physiotherapy practice. Ultrasonics 2008; 48(4):321–9.
17. Watson T, Young S. Therapeutic ultrasound. In: Watson T, editor. Electrotherapy: evidence based practice. Edinburgh (Scotland): Churchill-Livingstone, Elsevier; 2008.
18. Maier M, Tischer T, Milz S, et al. Dose-related effects of extracorporeal shock waves on rabbit quadriceps tendon integrity. Arch Orthop Trauma Surg 2002; 122:436–41.
19. Rompe JD, Kirkpatrick CJ, Kullmer K, et al. Dose-related effects of shock waves on rabbit tendon Achilles—A sonographic and histological study. J Bone Joint Surg Br 1998;80:546–52.
20. Bosch G, de Mos M, van Binsbergen R, et al. The effect of focused extracorporeal shock wave therapy on collagen matrix and gene expression in normal tendons and ligaments. Equine Vet J 2009;41:335–41.

21. Tam KF, Cheung WH, Lee KM, et al. Delayed stimulatory effect of low-intensity shockwaves on human periosteal cells. Clin Orthop Relat Res 2005;438:260–5.
22. Rompe JD. Letter to the editor: shock wave therapy for chronic Achilles tendon pain: a randomized placebo-controlled trial. Clin Orthop Relat Res 2006;445: 276–7.
23. Saxena A, Fournier M, Gerdesmeyer L, et al. Comparison between extracorporeal shockwave therapy, placebo ESWT and endoscopic plantar fasciotomy for the treatment of chronic plantar heel pain in the athlete. Muscles Ligaments Tendons J 2013;2(4):312–6.
24. Mittermayr R, Hartinger J, Antonic V, et al. Extracorporeal shock wave therapy (ESWT) minimizes ischemic tissue necrosis irrespective of application time and promotes tissue revascularization by stimulating angiogenesis. Ann Surg 2011; 253:1024–32.
25. Hausdorf J, Lemmens MA, Kaplan S, et al. Extracorporeal shockwave application to the distal femur of rabbits diminishes the number of neurons immunoreactive for substance P in dorsal root ganglia L5. Brain Res 2008;1207:96–101.
26. Weihs AM, Fuchs C, Teuschl AH, et al. Shockwave treatment enhances cell proliferation and improves wound healing by ATP release coupled extracellular signal-regulated kinase (ERK) activation. J Biol Chem 2014;289(39):27090–104. http://dx.doi.org/10.1074/jbc.M114.580936.
27. Vetrano M, d'Alessandro F, Torrisi MR, et al. Extracorporeal shock wave therapy promotes cell proliferation and collagen synthesis of primary cultured human tenocytes. Knee Surg Sports Traumatol Arthrosc 2011;19:2159–68.
28. Hayashi D, Kawakami K, Ito K, et al. Low-energy extracorporeal shock wave therapy enhances skin wound healing in diabetic mice: a critical role of endothelial nitric oxide synthase. Wound Repair Regen 2012;20:887–95.
29. Kuo YR, Wang CT, Wang FS, et al. Extracorporeal shock-wave therapy enhanced wound healing via increasing topical blood perfusion and tissue regeneration in a rat model of STZ-induced diabetes. Wound Repair Regen 2009;17:522–30.
30. Dumfarth J, Zimpfer D, Vogele-Kadletz M, et al. Prophylactic low-energy shock wave therapy improves wound healing after vein harvesting for coronary artery bypass graft surgery: a prospective, randomized trial. Ann Thorac Surg 2008; 86:1909–13.
31. Yan X, Zeng B, Chai Y, et al. Improvement of blood flow, expression of nitric oxide, and vascular endothelial growth factor by low-energy shockwave therapy in random-pattern skin flap model. Ann Plast Surg 2008;61:646–53.
32. Takahashi N, Wada Y, Ohtoori S, et al. Application of shock waves to rat skin decreases calcitonin gene-related peptide immunoreactivity in dorsal root ganglion neurons. Neuroscience 2003;107:81–4.
33. Peers KH. Extracorporeal shock wave therapy in chronic Achilles and patellar tendinopathy [Dissertation or thesis]. KU Leuven; 2003 (ISBN: 9058673049)\.
34. Kountouris A, Cook J. Rehabilitation of Achilles and patellar tendinopathies. Best Pract Res Clin Rheumatol 2007;21:295–316.
35. Rasmussen S, Christensen M, Mathiesen I, et al. Shockwave therapy for chronic Achilles tendinopathy: a double-blind, randomized clinical trial of efficacy. Acta Orthop 2008;79(2):249–56.
36. Magnussen RA, Dunn WR, Thomson AB. Nonoperative treatment of midportion Achilles tendinopathy: a systematic review. Clin J Sport Med 2009;19:54–64.
37. Saxena A, Ramdath S, O'Halloran P, et al. Extra-corporeal pulsed-activated therapy ("EPAT" sound wave) for Achilles tendinopathy: a prospective study. J Foot Ankle Surg 2011;50(3):315–9.

38. Sems A, Dimeff R, Iannotti JP. Extracorporeal shock wave therapy in the treatment of chronic tendinopathies. J Am Acad Orthop Surg 2006;14(4):195–204.
39. Gerdesmeyer L, Frey C, Vester J, et al. Radial extracorporeal shock wave therapy is safe and effective in the treatment of chronic recalcitrant plantar fasciitis results of a confirmatory randomized placebo- controlled multicenter study. Am J Sports Med 2008;36:2100–9.
40. Ibrahim MI, Donatelli RA, Schmitz C, et al. Chronic plantar fasciitis treated with two sessions of radial extracorporeal shock wave therapy. Foot Ankle Int 2010; 31:391–7.
41. Marks W, Jackiewicz A, Witkowski Z, et al. Extracorporeal shock-wave therapy (ESWT) with a new-generation pneumatic device in the treatment of heel pain. A double blind randomised controlled trial. Acta Orthop Belg 2008;74:98–101.
42. Greve JM, Grecco MV, Santos-Silva PR. Comparison of radial shockwaves and conventional physiotherapy for treating plantar fasciitis. Clinics (Sao Paulo) 2009;64:97–103.
43. Hsu WH, Lai LJ, Chang HY, et al. Effect of shockwave therapy on plantar fasciopathy A biomechanical prospective. Bone Joint J 2013;95-B(8):1088–93.
44. Lin TC, Lin CY, Chou CL, et al. Achilles tendon tear following shock wave therapy for calcific tendinopathy of the Achilles tendon: a case report. Phys Ther Sport 2012;13(3):189–92.
45. Barnes DE. Ultrasonic energy in tendon treatment. Op Tech Orthopaed 2013;23: 78–83.
46. Barnes DE, Beckley JM, Smith J. Percutaneous ultrasonic tenotomy for chronic elbow tendinosis: a prospective study. J Shoulder Elbow Surg 2014;24:67–73.
47. Koh JS, Mohan PC, Howe TS, et al. Fasciotomy and surgical tenotomy for recalcitrant lateral elbow tendinopathy. Early clinical experience with a novel device for minimally invasive percutaneous microresection. Am J Sports Med 2013;41: 636–44.
48. Patel MM. A novel treatment method for refractory plantar fasciitis. Am J Orthop, in press.
49. Packer M, Fishkind WJ, Fine H, et al. The physics of phaco: a review. J Cataract Refract Surg 2005;31:424–31.
50. Smith J, Finnoff JT. Diagnosis and interventional musculoskeletal ultrasound. Part 1. Fundamentals. PM R 2009;1:64–75.
51. Smith J, Finnoff JT. Diagnosis and interventional musculoskeletal ultrasound. Part 2. Clinical applications. PM&R 2009;1:162–77.