CURRENT CONCEPTS REVIEW

# The Role of Extracorporeal Shockwave Treatment in Musculoskeletal Disorders

Daniel Moya, MD, Silvia Ramón, MD, PhD, Wolfgang Schaden, MD, Ching-Jen Wang, MD, Leonardo Guiloff, MD, and Jai-Hong Cheng, MD


- Increasing evidence suggests that extracorporeal shockwave treatment (ESWT) is safe and effective for treating several musculoskeletal disorders.
- Two types of technical principles are usually included in ESWT: focused ESWT (F-ESWT) and radial pressure waves (RPW). These 2 technologies differ with respect to their generation devices, physical characteristics, and mechanism of action but share several indications.
- Strong evidence supports the use of ESWT in calcifying tendinopathy of the shoulder and plantar fasciitis.
- The best evidence for the use of ESWT was obtained with low to medium energy levels for tendon disorders as well as with a high energy level for tendon calcification and bone pathologies in a comprehensive rehabilitation framework.


Shockwave therapy was originally developed to disintegrate urinary stones 4 decades ago[1]. Since then, there has been remarkable progress regarding the knowledge of its biological and therapeutic effects. Its mechanism of action is based on acoustic mechanical waves that act at the molecular, cellular, and tissue levels to generate a biological response[2].

Increasing evidence suggests that extracorporeal shockwave treatment (ESWT) is safe and effective for treating several musculoskeletal disorders[3-5]. The purpose of this article was to provide current evidence on the physical and biological principles, mechanism of action, clinical indications, and controversies of ESWT.

## Physical Principles and Wave Generation

Two types of technical principles are included in ESWT—focused ESWT (F-ESWT) and radial pressure waves (RPW), which are often referred to in the literature as radial shockwaves. These 2 technologies differ in their generation devices, physical characteristics, and mechanism of action, but they share several indications.

As shown in Figure 1, the following 3 shockwave-generation principles are used for F-ESWT[6,7]:

1. Electrohydraulic sources (Fig. 1-A) produce a plasma bubble by high-voltage discharge between 2 electrodes in water at the focus closest to a paraellipsoidal reflector. The plasma expansion generates a shock front, which is reflected off the reflector and focused on a second focus at the target tissue.

2. Electromagnetic sources (Fig. 1-B) with flat or cylindrical coils are also used. In the first system, a high-voltage pulse is sent through a coil, which is opposite a metallic membrane. The coil produces a magnetic field, resulting in a sudden deflection of the membrane and generating pressure waves in a fluid. The waves are focused by a lens and steepen into a shockwave near the focus. The second electromagnetic generation source consists of a cylindrical coil and metallic membrane that is arranged inside a fluid-filled parabolic reflector. The

**Disclosure:** The authors indicated that no external funding was received for any aspect of this work. On the **Disclosure of Potential Conflicts of Interest** forms, *which are provided with the online version of the article*, one or more of the authors checked "yes" to indicate that the author had a patent and/or copyright, planned, pending, or issued, broadly relevant to this work and "yes" to indicate that the author had other relationships or activities that could be perceived to influence, or have the potential to influence, what was written in this work (http://links.lww.com/JBJS/E569).

membrane is accelerated away from the coil by a magnetic field. An acoustic pulse emerges radially, and it is concentrated onto the focus of the system after reflection off the reflector.

3. Piezoelectric sources (Fig. 1-C) produce shockwaves by a high-voltage discharge across a pattern of piezoelectric elements mounted on the inner surface of a spherical backing that is placed inside a fluid-filled cavity. Each element expands, generating a pressure pulse that propagates toward the center, or focal region, of the arrangement. Superposition of all pressure pulses and nonlinear effects produce a shockwave at focal region.

In RPW generators (Fig. 1-D), compressed air accelerates a projectile inside a cylindrical guiding tube. When the projectile hits an applicator at the end of the tube, a pressure wave is produced and radially expands into the target tissue. These devices do not emit shockwaves[8] because the rise times of the pressure pulses are too long and the pressure outputs are too low (Fig. 2). Nevertheless, RPW may induce acoustic cavitation[9].

The modes of action and the effects of RPW on living tissue may differ from those of focused shockwaves because bioeffects are related to the pressure waveform. F-ESWT and RPW may complement each other. While RPW is suitable for treating large areas, focused shockwaves can be concentrated deep inside the body.

## Mechanism of Action

Despite the clinical success of the treatment, the mechanism of action of ESWT remains unknown. In 1997, Haupt proposed the following 4 possible mechanisms of reaction phases of ESWT on tissue[10].

1. Physical phase: This phase indicates that the shockwave causes a positive pressure to generate absorption, reflection, refraction, and transmission of energy to tissues and cells[11]. Additional studies demonstrated that ESWT produces a tensile force by the negative pressure to induce the physical effects, such as cavitation, increasing the permeability of cell membranes and ionization of biological molecules. Meanwhile, many signal transduction pathways are activated, including the mechanotransduction signaling

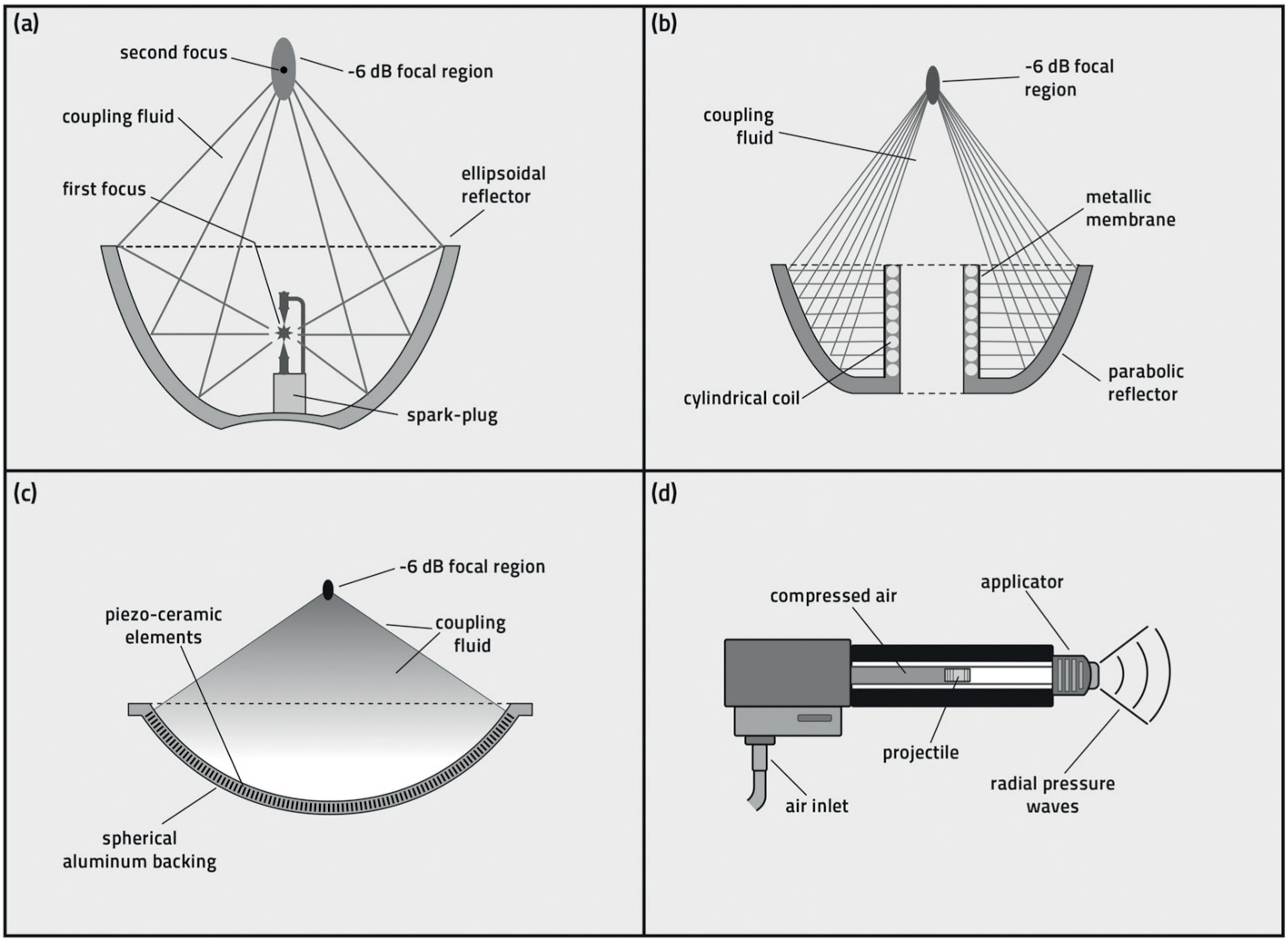


Fig. 1

**Figs. 1-A through 1-D** Illustrations of an electrohydraulic (**Fig. 1-A**), an electromagnetic (**Fig. 1-B**), and a piezoelectric shockwave source (**Fig. 1-C**) and a radial pressure wave source (**Fig. 1-D**). The −6 dB region is defined as the volume within which the positive pressure is at least 50% of its maximum.

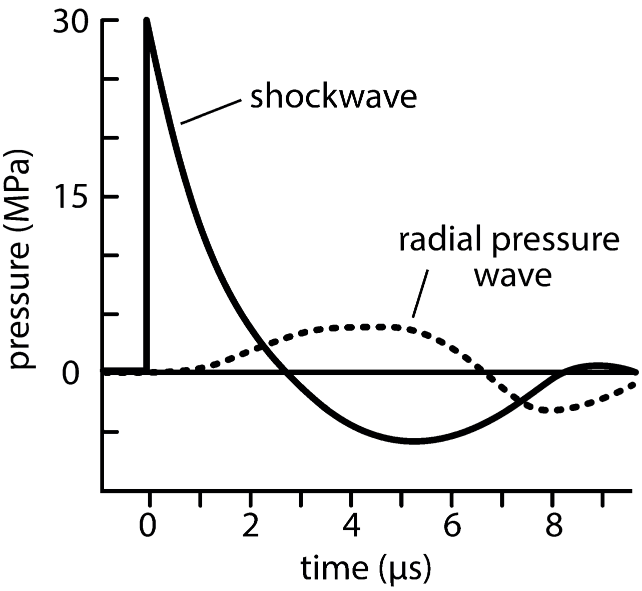


Fig. 2
Illustration showing the difference in pressure waveform between a shockwave and a radial pressure wave as used in medical applications.

pathway, the extracellular signal-regulated kinase (ERK) signaling pathway, focal adhesion kinase (FAK) signaling pathway, and Toll-like receptor 3 (TLR3) signaling pathway, to regulate gene expressions[2,5,12-14].

2. Physicochemical phase: ESWT stimulates cells to release biomolecules, such as adenosine triphosphate (ATP), to activate cell signal pathways[15,16].

3. Chemical phase: In this phase, shockwaves alter the functions of ion channels in the cell membrane and the calcium mobilization in cells[17,18].

4. Biological phase: Previous studies have shown that ESWT modulates angiogenesis (vWF [von Willebrand factor], vascular endothelial growth factor [VEGF], endothelial nitric oxide synthase [eNOS], and proliferating cell nuclear antigen [PCNA]), anti-inflammatory effects (soluble intercellular adhesion molecule 1 [sICAM] and soluble vascular cell adhesion molecule 1 [sVCAM]), wound-healing (Wnt3, Wnt5a, and beta-catenin), and bone-healing (bone morphogenetic protein [BMP]-2, osteocalcin, alkaline phosphatase, dickkopf-related protein 1 [DKK-1], and insulin-like growth factor [IGF]-1)[18-22].

The effects of ESWT are summarized in Table I, with new functional proteins induced by ESWT promoting a chondroprotective effect, neovascularization, anti-inflammation, anti-apoptosis, and tissue and nerve regeneration[2,12-14,16,19,22-52]. Furthermore, ESWT stimulates a shift in the macrophage phenotype from M1 to M2 and increases T-cell proliferation in the effect of immunomodulation[27,28]. ESWT activates the TLR3 signaling pathway to modulate inflammation by controlling the expression of interleukin (IL)-6 and IL-10 as well as improves the treatment of ischemic muscle[12,13].

**TABLE I Overview of Effects and Functional Proteins After ESWT***

| | Upregulation Factors | Downregulation Factors |
|---|---|---|
| Chondroprotective effect[2,14,16,29-40] | BMP-2, 3, 4, 7; IGF-1; TGFβ-1; VEGF; Wnt3; RUNX2; osteocalcin; alkaline phosphatase; osteopontin; FAK; ERK1/2; c-Fos; c-Jun; p38 MAPK; P2X7 receptor; SOX9; PDGF; b-FGF; FGF-2; Ras; substance P; prostaglandin E(2); Hsp70 | DKK1, Wnt5a, calcitonin gene-related peptide, miR-138 |
| Neovascularization[25,43-45] | VEGF, Flt1, Flt2, CD31, vWF, FGF, PlGF, KDR, PCNA | |
| Anti-inflammation[12,13,22,25,46] | TGFβ-1, TLR3, eNOS, nNOS, IL-10, IL-6, IL-8, cyclophilin B, cyclophilin A, EGF-like domains 2, IFN-β1 | sICAM, sVCAM, iNOS, IL-18, TNFα, NF-kB |
| Anti-apoptosis[25,47] | Bcl2, heme oxygenase (HO)-1, NAD(P)H quinone oxidoreductase-1 | Bax, cleaved caspase 3, cleaved PARP, γ-H2AX, NOX1, NOX2, TUNEL activity |
| Tissue and nerve regeneration[35,48-52] | COL1A1, COL2A1, MMP2, MMP9, glycosaminoglycan, collagen type III, S100b, p75, c-Jun, GFAP, activating transcription factor 3 (ATF3), growth-associated phosphoprotein (GAP-43) | MMP-1, MMP-13, myelin marker P0 |

*BMP = bone morphogenetic protein, IGF = insulin-like growth factor, TGF = transforming growth factor, VEGF = vascular endothelial growth factor, RUNX2 = runt-related transcription factor 2, FAK = focal adhesion kinase, ERK = extracellular signal-regulated kinase, MAPK = mitogen-activated protein kinase, PDGF = platelet-derived growth factor, FGF = fibroblast growth factor, Hsp = heat-shock protein, DKK = dickkopf-related protein, miR = microRNA, Flt = FMS-like tyrosine kinase, vWF = von Willebrand factor, PlGF = phosphatidylinositol-glycan biosynthesis class-F protein, KDR = kinase insert domain receptor, PCNA = proliferating cell nuclear antigen, TLR = Toll-like receptor, NOS = nitric oxide synthase, eNOS = endothelial NOS, nNOS = neuronal NOS, IL = interleukin, EGF = epidermal growth factor, IFN = interferon, sICAM = soluble intercellular adhesion molecule, sVCAM = soluble vascular cell adhesion molecule, iNOS = inducible NOS, TNFα = tumor necrosis factor alpha, NF-kB = nuclear factor kappa B, Bcl = B-cell lymphoma, NAD = nicotinamide adenine dinucleotide, PARP = poly(ADP-ribose) polymerase, H2AX = H2A histone family member X, TUNEL = terminal deoxynucleotidyl transferase-mediated dUTP nick end labeling, COL1A1 = collagen type-1 alpha 1, COL2A1 = collagen type-2 alpha 1, MMP = matrix metalloproteinase, and GFAP = glial fibrillary acidic protein.

Finally, it appears that ESWT participates in mechanotransduction, producing biological responses through mechanical stimulation on tissues[2,4,7,26].

## Clinical Indications

ESWT is indicated in chronic tendinopathies in which conventional conservative treatment is considered unsatisfactory after a prolonged and comprehensive management or as an alternative to surgery in patients with nonunion. ESWT is a noninvasive alternative in select cases when the indication for surgical treatment arises.

The International Society for Medical Shockwave Treatment (ISMST) has developed a list of approved clinical indications that are based on the strength of the supporting evidence[53]. The recommendations for ESWT indications and contraindications are summarized in Table II and Table III, respectively.

**TABLE II Grades of Recommendations According to Clinical Indications for ESWT**

| | | Studies* | | | | |
|---|---|---|---|---|---|---|
| | | Positive | | Negative | | |
| Pathology | Technology | RCTs | Reviews, Systematic Reviews, and Meta-Analyses | RCTs | Reviews, Systematic Reviews, and Meta-Analyses | Grade of Recommendation† |
| Calcifying tendinopathy of the shoulder | Focused | Gerdesmeyer et al.[58], Cosentino et al.[59], Hsu et al.[60], and Rompe et al.[69] | Moya et al.[55], Ioppolo et al.[61], Bannuru et al.[62], Huisstede et al.[63], Louwerens et al.[64], Speed[65], and Verstraelen et al.[66] | Albert et al.[56] and Kim et al.[67] | | A |
| Calcifying tendinopathy of the shoulder | Radial | Cacchio et al.[57] | | | Moya et al.[55], Bannuru et al.[62], Huisstede et al.[63], Speed[65], and Verstraelen et al.[66] | I |
| Noncalcifying tendinopathy of the shoulder | Focused or radial | | | Speed et al.[71] and Engebretsen et al.[72] | Moya et al.[55], Bannuru et al.[62], Huisstede et al.[63], and Speed[65] | C |
| Lateral epicondylopathy of the elbow | Focused or radial | Pettrone and McCall[85], Lee et al.[86], and Radwan et al.[87] | Thiele et al.[80] and Rompe and Maffulli[84] | Speed et al.[79] | Sims et al.[81], Buchbinder et al.[82], and Dingemanse et al.[83] | B |
| Greater trochanter pain syndrome | Radial | Rompe et al.[88] and Furia et al.[89] | Mani-Babu et al.[90] | | | B |
| Patellar tendinopathy | Focused or radial | Wang et al.[96], Furia et al.[97], and Peers et al.[99] | Mani-Babu[90], Leal et al.[91], Larsson et al.[94], and Everhart et al.[98] | Zwerver et al.[101] and Thijs et al.[102] | | B |
| Achilles tendinopathy | Focused or radial | Rasmussen et al.[110], Furia[111], Furia[112], Rompe et al.[113], and Rompe et al.[114] | Mani-Babu et al.[90], Gerdesmeyer et al.[108], Al-Abbad and Simon[115], Kearney and Costa[116], and Roche and Calder[117] | Costa et al.[109] | Scott et al.[105] | B |
| Plantar fasciitis | Focused or radial | Chuckpaiwong et al.[121], Wang et al.[122], Gerdesmeyer et al.[123], Ibrahim et al.[124], Gollwitzer et al.[125], Ogden et al.[126], Rompe et al.[127], Aqil et al.[128], Saxena et al.[133], Weil et al.[134], Thomas et al.[135], and Wang et al.[136] | Dizon et al.[130], Othman and Ragab[131], Radwan et al.[132], and Chen et al.[137] | Buchbinder et al.[119] and Haake et al.[120] | | A |
| Bone nonunion | Focused | Notarnicola et al.[155], Schaden et al.[157], and Lyon et al.[158] | Furia et al.[154], Kuo et al.[156], and Thiele et al.[160] | | | B |

*RCT = randomized controlled trial. †According to Wright[164], grade A indicates good evidence (Level-I studies with consistent findings) for or against recommending intervention; grade B, fair evidence (Level-II or III studies with consistent findings) for or against recommending intervention; grade C, poor-quality evidence (Level-IV or V studies with consistent findings) for or against recommending intervention; and grade I, there is insufficient or conflicting evidence not allowing a recommendation for or against intervention.

**TABLE III ESWT Contraindications**

| ESWT Contraindications* | |
|---|---|
| High-Energy Focused Shockwaves | Low-Energy Focused and Radial Shockwaves |
| 1. Lung tissue in the treatment area | 1. Malignant tumor in the treatment area |
| 2. Malignant tumor in the area | 2. Fetus in the treatment area |
| 3. Epiphyseal plate in the area | |
| 4. Brain or spine in the area | |
| 5. Severe coagulopathy | |
| 6. Fetus in the treatment area | |

*According to the International Society for Medical Shockwave Treatment[53].

After ESWT, a comprehensive post-treatment schedule, individualized for each pathology and each patient's clinical status, should be given to the patient including avoidance of the use of the anatomic structure, a specific exercise program, and instructions to avoid overload.

## *Shoulder Tendinopathies*

### Calcifying Tendinopathy of the Shoulder (CTS)

ESWT has emerged as an alternative therapy prior to invasive procedures when conservative treatment has failed as described for Gärtner type-I or II rotator cuff calcifications[54,55] (Fig. 3). The rate of successful reabsorption reported by different authors has a very wide range[56-66].

Gerdesmeyer et al.[58], in a multicenter randomized controlled trial (RCT) that included 144 patients, reported significantly better results in patients treated with F-ESWT, both low and high energy, compared with placebo, resulting in improvement with respect to pain, shoulder function, and calcium resorption in 86% in the high-energy group at 1 year compared with 37% in the low-energy group and 25% in the placebo ESWT group. Cosentino et al.[59], in a single-blind trial using F-ESWT, reported a significant increase in shoulder function, a decrease in pain compared with placebo, and calcium resorption of 71% by using F-ESWT, at 6 months. Hsu et al.[60], in an RCT, achieved good or excellent results in 87.9% of patients treated with high-energy F-ESWT.

Cacchio et al.[57] obtained a surprisingly high rate of reabsorption using RPW (86.6% complete and 13.4% partial resorption) at the 6-month follow-up; however, most studies have considered that high-energy F-ESWT is more likely to result in better radiographic and clinical outcomes[55,56,58-66].

Several systematic reviews and meta-analyses have demonstrated that high-energy F-ESWT is a safe, effective treatment for CTS[61-66].

Kim et al.[67] compared RPW with ultrasound-guided needling and reported that the latter treatment method was more effective in functional restoration and pain relief in the short term. However, Moya et al.[68] pointed out numerous methodological flaws in that study. There was missing information about the ESWT device used (focused or radial), methodological

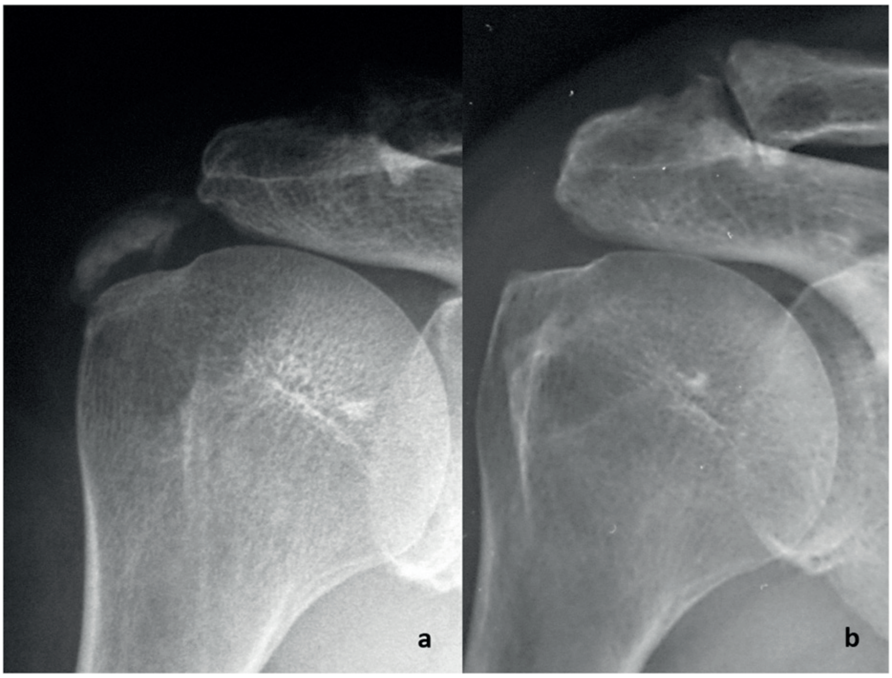


Fig. 3
Anteroposterior radiographs of a right shoulder with a Gärtner type-II calcification of the supraspinatus before focused shockwave treatment (**Fig. 3-A**) and at 3 months after treatment (**Fig. 3-B**), showing that the calcification has disappeared.

explanations were short and imprecise, the point of maximum tenderness was treated instead of focusing on topographic anatomy or locating calcium deposits with fluoroscopy or ultrasound, and the ESWT treatment protocol was nonstandard[68].

Rompe et al.[69] and Rebuzzi et al.[70] compared F-ESWT with open and arthroscopic surgery in CTS, respectively. They concluded that the results are comparable and that high-energy F-ESWT should be the first choice when conservative treatment has failed, because of its noninvasiveness.

In summary, given its efficacy in pain reduction[55,56,58-65,69,70] and functional outcomes[55,58,61-66,69,70], resorption rate[55,58-61,63,64,66,69], safety[55,59,60,64], noninvasiveness[55,69,70], reduced recovery time[55], and cost-effectiveness[55], we consider that high-energy F-ESWT is the treatment of choice in CTS when conservative treatment has failed.

**Noncalcifying Tendinopathy of the Shoulder**

Unlike CTS, the treatment of noncalcified tendinopathies with shockwaves is controversial[71]. Both favorable and poorly performing studies in many cases present inadequate inclusion criteria (wide age ranges, heterogeneous populations, and insufficient diagnostic evaluations). It is inadmissible to consider "subacromial pain"[72] or "non-specific shoulder pain"[73] as a diagnosis of shoulder disease if all possible differential diagnoses have not been ruled out. This confusion is reflected in the results of the meta-analyses and systematic reviews[62,63,65].

Huisstede et al.[63] found no strong evidence to support the efficacy of ESWT to treat noncalcific rotator cuff tendinosis beyond the applied energy level. Speed[65] did not support low-dose or high-dose F-ESWT.

We are unable to recommend the use of ESWT in noncalcific tendinopathy of the shoulder because of the lack of compelling evidence.

***Lateral Epicondylopathy of the Elbow***

There are many therapeutic options for treating lateral epicondylopathy. The existing evidence does not clearly support the efficacy of any of the available treatment methods for this clinical condition[74-79]. ESWT is not the exception[79], although it was approved by the U.S. Food and Drug Administration (FDA) for treating this disease in 2002[80].

Several systematic reviews and meta-analyses have shown conflicting evidence[81-83]. It is difficult to interpret the data because of the variety of study designs and the use of different shockwave devices[84].

Pettrone and McCall[85] reported a significant improvement with respect to pain and function in the active treatment group at 6 and 12 months compared with the placebo group in a study with Level-I evidence.

In a review study by Thiele et al.[80], the authors stated that several clinical trials have achieved very good results with the use of ESWT for lateral epicondylopathy of the elbow. That review only included Level-I studies using focused ESWT and RPW, and the authors concluded that lateral epicondylopathy is a primary indication for ESWT.

Lee et al.[86] found similar outcomes when comparing steroid injections with ESWT in lateral and medial epicondylopathy. Radwan et al.[87] found no significant differences between F-ESWT and percutaneous tenotomy.

Although the strength of the supporting evidence is not strong, no method to treat lateral epicondylopathy is backed by studies with a high level of evidence. As the benefits largely exceed any potential harm, we recommend the use of radial or focused ESWT technologies when conventional rehabilitation treatment has failed.

***Greater Trochanteric Pain Syndrome***

There is no agreement about the optimal management for greater trochanteric pain syndrome[88]. Numerous conservative treatments (nonsteroidal anti-inflammatory drugs, physiotherapy, and corticosteroid injections) have been recommended[88].

Two studies provided Level-II and III evidence for RPW effectiveness in 74% of patients at 15 months[88] and 78.8% at 12 months[89], respectively.

Rompe et al.[88] compared RPW with 2 other treatment methods, steroid injection and home training exercise, in a quasi-RCT. Although RPW was inferior to steroid injection at 1 month, RPW demonstrated better outcomes at 4 months compared with steroid injection and home exercise training, and it matched home training at 15 months[88]. Furia et al.[89] compared RPW and nonoperative therapy in patients with greater trochanteric pain syndrome. The RPW group had significant improvement with respect to pain, function, and Roles and Maudsley scales than the standard treatment group at 12 months[89].

Although the available evidence on ESWT in greater trochanteric pain syndrome is limited, RPW appears more effective than a home exercise program and local corticosteroid injection after short-term and mid-term follow-up (up to 15 months) of greater trochanteric pain syndrome[88-90].

***Patellar Tendinopathy***

Patellar tendinopathy treatment represents a challenge[91]. There is no evidence-based protocol for the appropriate management of patellar tendinopathy[90,92-95]. Eccentric training appears to be the first-line treatment[92-95].

New therapies, such as prolotherapy, dry-needling, platelet-rich plasma (PRP), cell therapy, or hyaluronic acid, may offer alternatives to standard treatments[93,94].

Promising results have been shown with ESWT[90,91,96-100]. Wang et al.[96] compared F-ESWT and conservative treatment in an RCT and obtained good or excellent results in 90% of the ESWT group at the 2 to 3-year follow-up evaluation compared with 50% in the conservative treatment group. Furia et al.[97] compared RPW and standard treatment in a retrospective study at 1 year and reported satisfactory results in 75.8% of patients receiving a single session of low-energy radial pressure waves compared with 17.2% in other nonoperative therapies.

By contrast, in an RCT, Zwerver et al.[101] compared real and placebo piezoelectric ESWT in athletes and did not find significant differences between the groups in terms of pain and function at 22 weeks. Another recent RCT on 52 athletes diagnosed with patellar tendinopathy evaluated the effect of ESWT or sham ESWT in addition to an eccentric training program and did not find differences at 6 months of follow-up[102].

However, these studies describing poor results with the use of ESWT included certain features and methodological errors such as: no complementary studies were performed to rule out calcification or partial rupture with a different prognosis[101,102]; applying ESWT with a piezoelectric device[101,102]; adapting the ESWT intensity to patient tolerance instead of a specific therapeutic energy level[101]; high energy levels[101]; allowing for training and competition during and after ESWT treatment instead of removing the patient from sports[101,102]; and ESWT as a solitary treatment not combined with exercise[101].

Peers et al.[99] retrospectively compared F-ESWT with surgery in 28 patients at an average of 24 months and showed excellent or good results according to the Roles and Maudsley score in 66% of the ESWT group, which was comparable with 58% in the surgery group. The authors concluded that F-ESWT in chronic patellar tendinopathy is an alternative to surgery, without resulting in incapacity, when conservative treatment fails[99].

Review of the literature shows that ESWT is safe and effective in the treatment of patellar tendinopathy[90,91,98]. Current evidence supports the use of F-ESWT and RPW for patellar tendinopathy with moderate or low-intensity protocols, especially in patients attempting to avoid an invasive intervention.

### *Achilles Tendinopathy*

Achilles tendinopathy affects active athletes as well as the sedentary population[103]. According to its anatomical location, it is classified into 2 categories, insertional and noninsertional or midportion tendinopathy.

Conservative treatment includes pain medication, heel lifts, eccentric exercises, physiotherapy, steroid and platelet-rich plasma injections, low-level laser therapy, and radiofrequency, among others[104-109]. Different shockwave sources and protocols have been used. A Level-I study with 48 patients compared piezoelectric F-ESWT and placebo ESWT and found better results for the ESWT group[110]. Furia reported good results for insertional[111] and noninsertional[112] Achilles tendinopathies with RPW.

In an RCT, Rompe et al.[113] demonstrated that RPW is more effective than eccentric loading exercises for insertional Achilles tendinopathy at the 15-month follow-up evaluation. Furthermore, there is demonstrated superior efficacy of combining eccentric loading and ESWT compared with eccentric loading alone in those patients[114].

Gerdesmeyer et al.[108] highlighted the efficacy of both F-ESWT and RPW in chronic Achilles tendinopathy. On the other hand[109], Costa et al. found no significant differences between the F-ESWT and control groups in terms of pain, function, and quality of life for 49 patients with Achilles tendinopathy at 3 months in a Level-I RCT[109]. Those authors concluded that there was no support for the use of ESWT in Achilles tendinopathy. ESWT was performed once a month for 3 months, instead of at weekly intervals as per the standard recommendations[4,5]. Two elderly patients had an Achilles rupture after ESWT, but, surprisingly, no complementary explorations were performed before treatment to rule out previous partial ruptures.

**TABLE IV ESWT Success Rate in the Treatment of Delayed Fracture-Healing and Nonunions**

| Study | No. of Patients | Material | Success Rate |
|---|---|---|---|
| Valchanou and Michailov[142] (1991) | 82 | Nonunions* | 84% |
| Rompe et al.[144] (2001) | 43 | Tibial and femoral diaphyseal and metaphyseal nonunions | 72% |
| Wang et al.[145] (2001) | 72 | Nonunions (41 femora, 19 tibiae, 7 humeri, 1 radius, 3 cubiti, and 1 metatarsal) | 80% |
| Schaden et al.[146] (2001) | 115 | 72 shaft fractures in long bones and 43 fractures in cancellous bones | 75.7% |
| Bara and Snyder[148] (2007) | 81 | 42 delayed unions and 39 nonunions (49 tibiae, 13 femora, 10 radial and ulnar bones, and 5 humeri) | 83% |
| Xu et al.[149] (2009) | 69 | Nonunions (22 femora, 28 tibiae, 13 humeri, 5 radii, and 1 ulna) | 75.4% |
| Cacchio et al.[152] (2009) | 126 | Long-bone nonunions | 71% |
| Elster et al.[150] (2010) | 192 | Tibia | 80.2% |
| Furia et al.[154] (2010) | 23 | Nonunion of proximal fifth metatarsal metaphyseal-diaphyseal fractures | 87% |
| Notarnicola et al.[155] (2010) | 58 | Carpal scaphoid nonunions | 75.9% |
| Zelle et al.[151] (2010) | 924 | Systematic review of 10 case series and 1 RCT including delayed union and nonunion | 76% |
| Kuo et al.[156] (2015) | 22 | Atrophic nonunions of the femoral shaft | 63.6% |

*Patient history, concomitant treatment, and follow-up were not specified.

Three systematic reviews[90,115,116] and 1 review[117] showed satisfactory evidence of the effectiveness of low-energy ESWT in insertional and noninsertional chronic Achilles tendinopathy after failure of conservative treatment and before considering surgery, especially in combination with eccentric loading.

### *Plantar Fasciitis*

Plantar fasciitis is a degenerative musculoskeletal disorder[118]. In 2002, Buchbinder et al.[119] found no evidence to support the use of ESWT in plantar fasciitis. In 2003, another RCT considered electromagnetic ESWT to be ineffective in this field[120].

Since then, several studies with a high level of evidence have supported both focused[121,122] and radial[123,124] technologies for this disorder. Gollwitzer et al.[125], in a study of the treatment of recalcitrant plantar fasciitis with an electromagnetic device, reported pain reduction in 69.2% of the patients in the ESWT group compared with 34.5% in the control group. Ogden et al.[126], in an RCT, concluded that electrohydraulic F-ESWT is effective and safe and that the clinical improvement lasts beyond 1 year. In a Level-I study, Wang et al.[122] compared F-ESWT with conservative treatment modalities. The shockwave group had excellent or good results in 82.7% of the patients compared with 55% in the control group at a follow-up of between 60 and 72 months; also, the shockwave group had a much lower recurrence rate.

Gerdesmeyer et al.[123], in an RCT, reported an overall success rate of 61% with RPW compared with 42.2% in the placebo group at 12 weeks.

Recently, a multicenter study[127] showed that the combination of a plantar fascia-specific stretching program with low-energy RPW achieves better results than RPW alone. Three meta-analyses[128-130] found that ESWT is effective for treating chronic plantar fasciitis. Aqil et al.[128] recommended the use of shockwave treatment in plantar fasciitis on the basis of its efficacy and safety.

Several studies have compared F-ESWT with surgery[131-134], supporting the use of shockwave treatment because of its effectiveness[128,132,134] and because patients can quickly resume full activities[131] and athletes have a chance to continue sports activities[133].

Since 2010, the American College of Foot and Ankle Surgeons has recommended ESWT as a treatment of choice for plantar fasciitis with or without a plantar spur when nonoperative treatment has failed[135].

### *Bone Disorders*

Haupt[10], in 1997, recognized the dynamic interaction between ESWT and bone. It was initially hypothesized that shockwaves

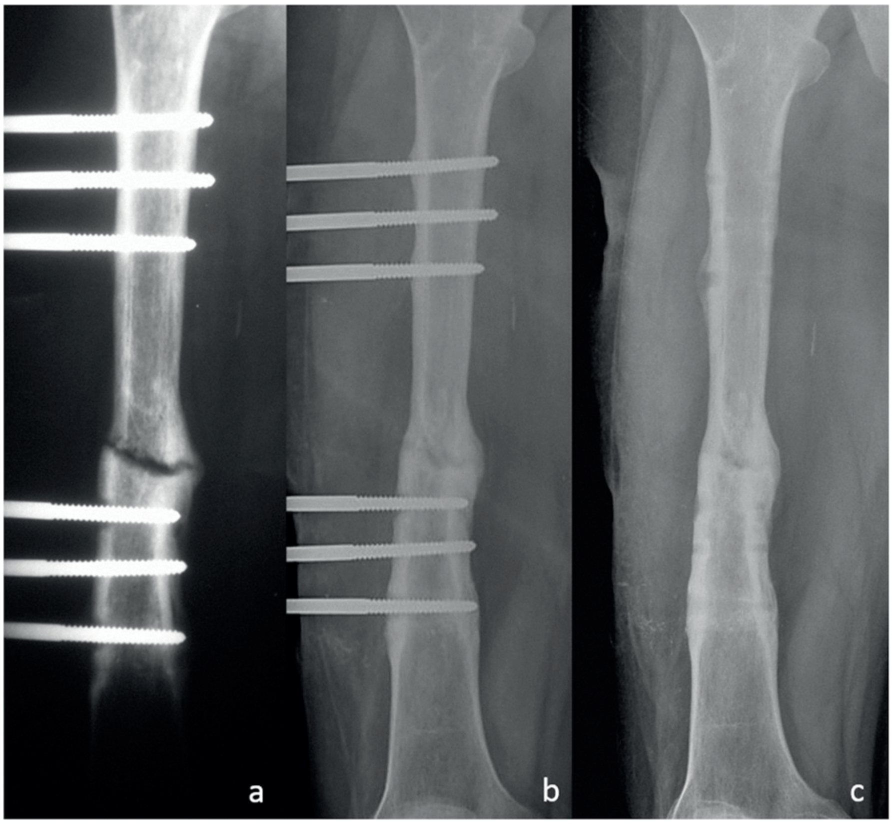


Fig. 4

**Figs. 4-A, 4-B, and 4-C** Anteroposterior radiographs of the right femur of a 37-year-old man who had sustained a femoral fracture in a motorcycle accident; the fracture was initially treated with an intramedullary nail, but it was revised 14 months later because of nonunion and an external fixator was applied. **Fig. 4-A** At 6 months after the second surgery, there were no signs of bone-healing. **Fig. 4-B** At 4 months after F-ESWT, a successful union of the fracture was evident. **Fig. 4-C** The final result after external fixator removal demonstrated complete healing.

created microlesions in treated bone. This appreciation completely changed when Wang et al.[19,20] demonstrated that shockwaves generate upregulation and expression of various pro-angiogenic and pro-osteogenic growth factors, stimulating bone-healing. Basic research has shown that because of mechanical forces delivered by shockwaves to the cells and to the extracellular matrix, messengers are liberated and activate different genes and groups of genes in the cell nucleus[50,136-140]. This phenomenon of biological conversion from a mechanical stimulus into electrochemical activity is called "mechanotransduction."[141]

The use of ESWT for nonhealing fractures was first reported, to our knowledge, in 1991 by Valchanou and Michailov[142]. Since then, several observations and trials have supported the efficacy of ESWT for nonunion and delayed fracture-healing[143-157] (Table IV).

Cacchio et al.[152], in a Level-I RCT, compared different ESWT high-energy levels (0.4 mJ/mm$^2$ [Group 1] and 0.7 mJ/mm$^2$ [Group 2]) and surgery (Group 3) for the treatment of hypertrophic long-bone nonunions and obtained success rates of 70%, 71%, and 73%, respectively, at 6 months. No adverse effects occurred in the ESWT groups compared with a 7% rate of complications in the surgical group.

Similar results were reported by Furia et al.[154], who observed that high-energy F-ESWT was as effective as intramedullary screw fixation in the treatment of nonunion of a fracture of the fifth metatarsal; however, screw fixation was more often associated with complications that frequently resulted in additional surgery.

Notarnicola et al.[155] found that the results of ESWT were comparable with those of surgical stabilization and bone graft for the treatment of carpal scaphoid pseudarthrosis.

Kuo et al.[156] reported that the success rate of ESWT was 63.6% in the treatment of atrophic nonunions of the femoral shaft and could be as high as 100% if applied within 12 months after the initial treatment. Poor results were associated with instability, a gap at the nonunion site of >5 mm, and atrophic nonunion.

As some Level-I and II evidence has demonstrated that the efficacy of ESWT is comparable with that of surgery for the treatment of nonunions[152,154,155], and ESWT is practically free of adverse effects and more economic, it may progressively be considered as the first choice in the treatment of stable nonunions with a gap of <5 mm in long bones (Fig. 4). For bone treatment, the basic principles of acute fracture management should be implemented after F-ESWT (immobilization, casting, and weight-bearing restrictions).

ESWT seems to be an effective option in adult osteochondritis dissecans[158-160], but further studies are required to determine long-term results.

## Economic and Administrative Considerations

We acknowledge that it is currently difficult to obtain reimbursement for ESWT in the United States. We hope that heightened awareness as to the efficacy of ESWT, as well as recognition of how ESWT can be a cost-saving measure, will lead to changes in reimbursement coverage.

Shockwave treatment is indicated when standard conservative treatment has failed, so its cost should be compared with the cost of surgery. Dubs[161] compared the efficacy and costs of ESWT with the usual treatments for CTS. In addition to demonstrating that ESWT was more efficacious, it also allowed for an average savings of US$2,000 per patient in comparison with alternative therapies.

Haake et al.[162] showed that the cost of treatment for CTS was between €2,700 and €4,300 per patient for ESWT compared with €13,400 to €23,450 for surgery and concluded that the cost of surgery was 5 to 7 times higher than ESWT. Ramón et al.[163] reported, in absolute numbers, a savings of approximately €2,000 per patient for ESWT compared with surgery for the treatment of calcifying tendinopathy of the shoulder.

## Overview

ESWT is considered to be an alternative to surgery for several chronic tendinopathies and nonunions because of its efficacy, safety, and noninvasiveness. The best evidence supporting the use of ESWT was obtained with low to medium levels of energy for tendon disorders as well as with a high energy level for tendon calcification and bone pathologies in a comprehensive rehabilitation framework.

Because of the variability in the treatment protocols, the methodological quality of many ESWT studies is limited. Further research from well-designed, high-quality studies is required to standardize the treatment parameters and demonstrate the optimal ESWT approach for health-care decision-making.

With adequate patient selection, appropriate indications, homogeneous ESWT therapeutic protocols, and proper application, ESWT could make a paramount contribution to noninvasive treatment of certain musculoskeletal disorders. ■

Note: The authors thank Dr. Achim M. Loske Mehling for his important contribution on the subject of physical principles and wave generation, and John Furia, MD, for his kind contribution on Achilles tendinopathy and on economic and administrative considerations.2

Daniel Moya, MD[1]
Silvia Ramón, MD, PhD[2]
Wolfgang Schaden, MD[3]
Ching-Jen Wang, MD[4]
Leonardo Guiloff, MD[5]
Jai-Hong Cheng, MD[4]

[1]Buenos Aires British Hospital, Buenos Aires, Argentina

[2]Hospital Quirón, Barcelona, Fundación García Cugat, Spain

[3]AUVA-Head Office, Vienna, Austria

[4]Chang Gung Memorial Hospital, Kaohsiung, Taiwan

[5]Clínica Arauco Salud, Santiago de Chile, Chile

E-mail addresses for D. Moya: drdanielmoya@yahoo.com.ar; drdanielmoya@gmail.com

ORCID iD for D. Moya: 0000-0003-1889-7699

## References

**1.** Chaussy C, Eisenberger F, Forssmann B. Extracorporeal shockwave lithotripsy (ESWL): a chronology. J Endourol. 2007 Nov;21(11):1249-53.

**2.** Cheng JH, Wang CJ. Biological mechanism of shockwave in bone. Int J Surg. 2015 Dec;24(Pt B):143-6. Epub 2015 Jun 25.

**3.** D Agostino MC, Frairia R, Romeo P, Amelio E, Berta L, Bosco V, Gigliotti S, Guerra C, Messina S, Messuri L, Moretti B, Notarnicola A, Maccagnano G, Russo S, Saggini R, Vulpiani MC, Buselli P. Extracorporeal shockwaves as regenerative therapy in orthopedic traumatology: a narrative review from basic research to clinical practice. J Biol Regul Homeost Agents. 2016 Apr-Jun;30(2):323-32.

**4.** Ioppolo F, Rompe JD, Furia JP, Cacchio A. Clinical application of shock wave therapy (SWT) in musculoskeletal disorders. Eur J Phys Rehabil Med. 2014 Apr;50 (2):217-30. Epub 2014 Mar 26.

**5.** Wang CJ. An overview of shock wave therapy in musculoskeletal disorders. Chang Gung Med J. 2003 Apr;26(4):220-32.

**6.** Cleveland RO, McAteer JA. Physics of shock-wave lithotripsy. In: Smith AD, Badlani G, Preminger GM, Kavoussi LR, editors. Smith's textbook of endourology. 3rd ed. Cichester: Wiley-Blackwell; 2012. p 529-58.

**7.** Loske AM. Medical and biomedical applications of shock waves. Cham, Switzerland: Springer International; 2017.

**8.** Cleveland RO, Chitnis PV, McClure SR. Acoustic field of a ballistic shock wave therapy device. Ultrasound Med Biol. 2007 Aug;33(8):1327-35. Epub 2007 Apr 27.

**9.** Császár NB, Angstman NB, Milz S, Sprecher CM, Kobel P, Farhat M, Furia JP, Schmitz C. Radial shock wave devices generate cavitation. PLoS One. 2015 Oct 28;10(10):e0140541.

**10.** Haupt G. Use of extracorporeal shock waves in the treatment of pseudarthrosis, tendinopathy and other orthopedic diseases. J Urol. 1997 Jul;158(1):4-11.

**11.** Ogden JA, Tóth-Kischkat A, Schultheiss R. Principles of shock wave therapy. Clin Orthop Relat Res. 2001 Jun;387:8-17.

**12.** Holfeld J, Tepeköylü C, Reissig C, Lobenwein D, Scheller B, Kirchmair E, Kozaryn R, Albrecht-Schgoer K, Krapf C, Zins K, Urbschat A, Zacharowski K, Grimm M, Kirchmair R, Paulus P. Toll-like receptor 3 signalling mediates angiogenic response upon shock wave treatment of ischaemic muscle. Cardiovasc Res. 2016 Feb 1;109 (2):331-43. Epub 2015 Dec 16.

**13.** Holfeld J, Tepeköylü C, Kozaryn R, Urbschat A, Zacharowski K, Grimm M, Paulus P. Shockwave therapy differentially stimulates endothelial cells: implications on the control of inflammation via toll-like receptor 3. Inflammation. 2014 Feb;37(1):65-70.

**14.** Xu JK, Chen HJ, Li XD, Huang ZL, Xu H, Yang HL, Hu J. Optimal intensity shock wave promotes the adhesion and migration of rat osteoblasts via integrin β1-mediated expression of phosphorylated focal adhesion kinase. J Biol Chem. 2012 Jul 27;287(31):26200-12. Epub 2012 May 31.

**15.** Yu T, Junger WG, Yuan C, Jin A, Zhao Y, Zheng X, Zeng Y, Liu J. Shockwaves increase T-cell proliferation and IL-2 expression through ATP release, P2X7 receptors, and FAK activation. Am J Physiol Cell Physiol. 2010 Mar;298(3):C457-64. Epub 2009 Nov 4.

**16.** Weihs AM, Fuchs C, Teuschl AH, Hartinger J, Slezak P, Mittermayr R, Redl H, Junger WG, Sitte HH, Rünzler D. Shock wave treatment enhances cell proliferation and improves wound healing by ATP release-coupled extracellular signal-regulated kinase (ERK) activation. J Biol Chem. 2014 Sep 26;289(39):27090-104. Epub 2014 Aug 12.

**17.** Jan CR, Huang JK, Tseng CJ. High-energy shock waves alter cytosolic calcium mobilization in single MDCK cells. Nephron. 1998;78(2):187-94.

**18.** Frairia R, Berta L. Biological effects of extracorporeal shock waves on fibroblasts. A review. Muscles Ligaments Tendons J. 2012 Apr 1;1(4):138-47.

**19.** Wang CJ, Wang FS, Yang KD, Weng LH, Hsu CC, Huang CS, Yang LC. Shock wave therapy induces neovascularization at the tendon-bone junction. A study in rabbits. J Orthop Res. 2003 Nov;21(6):984-9.

**20.** Wang CJ, Wang FS, Yang KD. Biological effects of extracorporeal shockwave in bone healing: a study in rabbits. Arch Orthop Trauma Surg. 2008 Aug;128(8):879-84. Epub 2008 Jun 17.

**21.** Kuo YR, Wang CT, Wang FS, Chiang YC, Wang CJ. 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 Jul-Aug;17(4):522-30.

**22.** Wang CJ, Yang YJ, Huang CC. The effects of shockwave on systemic concentrations of nitric oxide level, angiogenesis and osteogenesis factors in hip necrosis. Rheumatol Int. 2011 Jul;31(7):871-7. Epub 2010 Mar 16.

**23.** Wang CJ, Hsu SL, Weng LH, Sun YC, Wang FS. Extracorporeal shockwave therapy shows a number of treatment related chondroprotective effect in osteoarthritis of the knee in rats. BMC Musculoskelet Disord. 2013 Jan 28;14:44.

**24.** Mariotto S, de Prati AC, Cavalieri E, Amelio E, Marlinghaus E, Suzuki H. Extracorporeal shock wave therapy in inflammatory diseases: molecular mechanism that triggers anti-inflammatory action. Curr Med Chem. 2009;16(19):2366-72.

**25.** Fu M, Sun CK, Lin YC, Wang CJ, Wu CJ, Ko SF, Chua S, Sheu JJ, Chiang CH, Shao PL, Leu S, Yip HK. Extracorporeal shock wave therapy reverses ischemia-related left ventricular dysfunction and remodeling: molecular-cellular and functional assessment. PLoS One. 2011;6(9):e24342. Epub 2011 Sep 6.

**26.** Wang CJ. Extracorporeal shockwave therapy in musculoskeletal disorders. J Orthop Surg Res. 2012 Mar 20;7:11.

**27.** Abe Y, Ito K, Hao K, Shindo T, Ogata T, Kagaya Y, Kurosawa R, Nishimiya K, Satoh K, Miyata S, Kawakami K, Shimokawa H. Extracorporeal low-energy shockwave therapy exerts anti-inflammatory effects in a rat model of acute myocardial infarction. Circ J. 2014;78(12):2915-25. Epub 2014 Oct 2.

**28.** Yu TC, Liu Y, Tan Y, Jiang Y, Zheng X, Xu X. Shock waves increase T-cell proliferation or IL-2 expression by activating p38 MAP kinase. Acta Biochim Biophys Sin (Shanghai). 2004 Nov;36(11):741-8.

**29.** Chen YJ, Wurtz T, Wang CJ, Kuo YR, Yang KD, Huang HC, Wang FS. Recruitment of mesenchymal stem cells and expression of TGF-beta 1 and VEGF in the early stage of shock wave-promoted bone regeneration of segmental defect in rats. J Orthop Res. 2004 May;22(3):526-34.

**30.** Wang FS, Yang KD, Chen RF, Wang CJ, Sheen-Chen SM. Extracorporeal shock wave promotes growth and differentiation of bone-marrow stromal cells towards osteoprogenitors associated with induction of TGF-beta1. J Bone Joint Surg Br. 2002 Apr;84(3):457-61.

**31.** Wang FS, Yang KD, Kuo YR, Wang CJ, Sheen-Chen SM, Huang HC, Chen YJ. Temporal and spatial expression of bone morphogenetic proteins in extracorporeal shock wave-promoted healing of segmental defect. Bone. 2003 Apr;32(4):387-96.

**32.** Wang CJ, Wang FS, Ko JY, Huang HY, Chen CJ, Sun YC, Yang YJ. Extracorporeal shockwave therapy shows regeneration in hip necrosis. Rheumatology (Oxford). 2008 Apr;47(4):542-6.

**33.** Wang CJ, Sun YC, Wu CT, Weng LH, Wang FS. Molecular changes after shockwave therapy in osteoarthritic knee in rats. Shock Waves. 2016;26(1):45-51.

**34.** Wang CJ, Sun YC, Siu KK, Wu CT. Extracorporeal shockwave therapy shows site-specific effects in osteoarthritis of the knee in rats. J Surg Res. 2013 Aug;183 (2):612-9. Epub 2013 Feb 26.

**35.** Takahashi K, Yamazaki M, Saisu T, Nakajima A, Shimizu S, Mitsuhashi S, Moriya H. Gene expression for extracellular matrix proteins in shockwave-induced osteogenesis in rats. Calcif Tissue Int. 2004 Feb;74(2):187-93. Epub 2003 Nov 6.

**36.** Sun D, Junger WG, Yuan C, Zhang W, Bao Y, Qin D, Wang C, Tan L, Qi B, Zhu D, Zhang X, Yu T. Shockwaves induce osteogenic differentiation of human mesenchymal stem cells through ATP release and activation of P2X7 receptors. Stem Cells. 2013 Jun;31(6):1170-80.

**37.** Maier M, Averbeck B, Milz S, Refior HJ, Schmitz C. Substance P and prostaglandin E2 release after shock wave application to the rabbit femur. Clin Orthop Relat Res. 2003 Jan;406:237-45.

**38.** Yuen CM, Chung SY, Tsai TH, Sung PH, Huang TH, Chen YL, Chen YL, Chai HT, Zhen YY, Chang MW, Wang CJ, Chang HW, Sun CK, Yip HK. Extracorporeal shock wave effectively attenuates brain infarct volume and improves neurological function in rat after acute ischemic stroke. Am J Transl Res. 2015 Jun 15;7(6):976-94.

**39.** Ochiai N, Ohtori S, Sasho T, Nakagawa K, Takahashi K, Takahashi N, Murata R, Takahashi K, Moriya H, Wada Y, Saisu T. Extracorporeal shock wave therapy improves motor dysfunction and pain originating from knee osteoarthritis in rats. Osteoarthritis Cartilage. 2007 Sep;15(9):1093-6. Epub 2007 Apr 26.

**40.** Hu J, Liao H, Ma Z, Chen H, Huang Z, Zhang Y, Yu M, Chen Y, Xu J. Focal adhesion kinase signaling mediated the enhancement of osteogenesis of human mesenchymal stem cells induced by extracorporeal shockwave. Sci Rep. 2016 Feb 11;6:20875.

**41.** Wang CJ, Huang KE, Sun YC, Yang YJ, Ko JY, Weng LH, Wang FS. VEGF modulates angiogenesis and osteogenesis in shockwave-promoted fracture healing in rabbits. J Surg Res. 2011 Nov;171(1):114-9. Epub 2010 Feb 21.

**42.** Sun CK, Shao PL, Wang CJ, Yip HK. Study of vascular injuries using endothelial denudation model and the therapeutic application of shock wave: a review. Am J Transl Res. 2011 May 15;3(3):259-68. Epub 2011 Apr 8.

**43.** Yamaya S, Ozawa H, Kanno H, Kishimoto KN, Sekiguchi A, Tateda S, Yahata K, Ito K, Shimokawa H, Itoi E. Low-energy extracorporeal shock wave therapy promotes vascular endothelial growth factor expression and improves locomotor recovery after spinal cord injury. J Neurosurg. 2014 Dec;121(6):1514-25. Epub 2014 Oct 3.

**44.** Holfeld J, Tepeköylü C, Kozaryn R, Mathes W, Grimm M, Paulus P. Shock wave application to cell cultures. J Vis Exp. 2014 Apr 8;(86).

**45.** Holfeld J, Tepeköylü C, Blunder S, Lobenwein D, Kirchmair E, Dietl M, Kozaryn R, Lener D, Theurl M, Paulus P, Kirchmair R, Grimm M. Low energy shock wave therapy induces angiogenesis in acute hind-limb ischemia via VEGF receptor 2 phosphorylation. PLoS One. 2014 Aug 5;9(8):e103982.

**46.** Ciampa AR, de Prati AC, Amelio E, Cavalieri E, Persichini T, Colasanti M, Musci G, Marlinghaus E, Suzuki H, Mariotto S. Nitric oxide mediates anti-inflammatory action of extracorporeal shock waves. FEBS Lett. 2005 Dec 19;579(30):6839-45. Epub 2005 Nov 28.

**47.** Chen YL, Chen KH, Yin TC, Huang TH, Yuen CM, Chung SY, Sung PH, Tong MS, Chen CH, Chang HW, Lin KC, Ko SF, Yip HK. Extracorporeal shock wave therapy effectively prevented diabetic neuropathy. Am J Transl Res. 2015 Dec 15;7 (12):2543-60.

**48.** Waugh CM, Morrissey D, Jones E, Riley GP, Langberg H, Screen HR. In vivo biological response to extracorporeal shockwave therapy in human tendinopathy. Eur Cell Mater. 2015 May 15;29:268-80, discussion :280.

**49.** Han SH, Lee JW, Guyton GP, Parks BG, Courneya JP, Schon LCJJ. J.Leonard Goldner Award 2008. Effect of extracorporeal shock wave therapy on cultured tenocytes. Foot Ankle Int. 2009 Feb;30(2):93-8.

**50.** Dias dos Santos PR, De Medeiros VP, Freire Martins de Moura JP, da Silveira Franciozi CE, Nader HB, Faloppa F. Effects of shock wave therapy on glycosaminoglycan expression during bone healing. Int J Surg. 2015 Dec;24(Pt B):120-3. Epub 2015 Sep 30.

**51.** Schuh CM, Hercher D, Stainer M, Hopf R, Teuschl AH, Schmidhammer R, Redl H. Extracorporeal shockwave treatment: a novel tool to improve Schwann cell isolation and culture. Cytotherapy. 2016 Jun;18(6):760-70. Epub 2016 Apr 5.

**52.** Murata R, Ohtori S, Ochiai N, Takahashi N, Saisu T, Moriya H, Takahashi K, Wada Y. Extracorporeal shockwaves induce the expression of ATF3 and GAP-43 in rat dorsal root ganglion neurons. Auton Neurosci. 2006 Jul 30;128(1-2):96-100. Epub 2006 May 23.

**53.** International Society for Medical Shockwave Treatment. Consensus statement on ESWT indications and contraindications. https://www.shockwavetherapy.org/fileadmin/user_upload/dokumente/PDFs/Formulare/ISMST_consensus_statement_on_indications_and_contraindications_20161012_final.pdf. Accessed 2017 Nov 6.

**54.** Gärtner J, Simons B. Analysis of calcific deposits in calcifying tendinitis. Clin Orthop Relat Res. 1990 May;254:111-20.

**55.** Moya D, Ramón S, Guiloff L, Gerdesmeyer L. Current knowledge on evidence-based shockwave treatments for shoulder pathology. Int J Surg. 2015 Dec;24(Pt B):171-8. Epub 2015 Sep 9.

**56.** Albert JD, Meadeb J, Guggenbuhl P, Marin F, Benkalfate T, Thomazeau H, Chalès G. High-energy extracorporeal shock-wave therapy for calcifying tendinitis of the rotator cuff: a randomised trial. J Bone Joint Surg Br. 2007 Mar;89(3):335-41.

**57.** Cacchio A, Paoloni M, Barile A, Don R, de Paulis F, Calvisi V, Ranavolo A, Frascarelli M, Santilli V, Spacca G. Effectiveness of radial shock-wave therapy for calcific tendinitis of the shoulder: single-blind, randomized clinical study. Phys Ther. 2006 May;86(5):672-82.

**58.** Gerdesmeyer L, Wagenpfeil S, Haake M, Maier M, Loew M, Wörtler K, Lampe R, Seil R, Handle G, Gassel S, Rompe JD. Extracorporeal shock wave therapy for the treatment of chronic calcifying tendonitis of the rotator cuff: a randomized controlled trial. JAMA. 2003 Nov 19;290(19):2573-80.

**59.** Cosentino R, De Stefano R, Selvi E, Frati E, Manca S, Frediani B, Marcolongo R. Extracorporeal shock wave therapy for chronic calcific tendinitis of the shoulder: single blind study. Ann Rheum Dis. 2003 Mar;62(3):248-50.

**60.** Hsu CJ, Wang DY, Tseng KF, Fong YC, Hsu HC, Jim YF. Extracorporeal shock wave therapy for calcifying tendinitis of the shoulder. J Shoulder Elbow Surg. 2008 Jan-Feb;17(1):55-9.

**61.** Ioppolo F, Tattoli M, Di Sante L, Venditto T, Tognolo L, Delicata M, Rizzo RS, Di Tanna G, Santilli V. Clinical improvement and resorption of calcifications in calcific tendinitis of the shoulder after shock wave therapy at 6 months' follow-up: a systematic review and meta-analysis. Arch Phys Med Rehabil. 2013 Sep;94(9):1699-706. Epub 2013 Mar 13.

**62.** Bannuru RR, Flavin NE, Vaysbrot E, Harvey W, McAlindon T. High-energy extracorporeal shock-wave therapy for treating chronic calcific tendinitis of the shoulder: a systematic review. Ann Intern Med. 2014 Apr 15;160(8):542-9.

**63.** Huisstede BM, Gebremariam L, van der Sande R, Hay EM, Koes BW. Evidence for effectiveness of extracorporal shock-wave therapy (ESWT) to treat calcific and non-calcific rotator cuff tendinosis—a systematic review. Man Ther. 2011 Oct;16(5):419-33. Epub 2011 Mar 10.

**64.** Louwerens JK, Sierevelt IN, van Noort A, van den Bekerom MP. Evidence for minimally invasive therapies in the management of chronic calcific tendinopathy of the rotator cuff: a systematic review and meta-analysis. J Shoulder Elbow Surg. 2014 Aug;23(8):1240-9. Epub 2014 Apr 26.

**65.** Speed C. A systematic review of shockwave therapies in soft tissue conditions: focusing on the evidence. Br J Sports Med. 2014 Nov;48(21):1538-42. Epub 2013 Aug 5.

**66.** Verstraelen FU, In den Kleef NJ, Jansen L, Morrenhof JW. High-energy versus low-energy extracorporeal shock wave therapy for calcifying tendinitis of the shoulder: which is superior? A meta-analysis. Clin Orthop Relat Res. 2014 Sep;472(9):2816-25. Epub 2014 May 29.

**67.** Kim YS, Lee HJ, Kim YV, Kong CG. Which method is more effective in treatment of calcific tendinitis in the shoulder? Prospective randomized comparison between ultrasound-guided needling and extracorporeal shock wave therapy. J Shoulder Elbow Surg. 2014 Nov;23(11):1640-6. Epub 2014 Sep 12.

**68.** Moya D, Ramón S, d'Agostino MC, Leal C, Aranzabal JR, Eid J, Schaden W. Incorrect methodology may favor ultrasound-guided needling over shock wave treatment in calcific tendinopathy of the shoulder. J Shoulder Elbow Surg. 2016 Aug;25(8):e241-3.

**69.** Rompe JD, Zoellner J, Nafe B. Shock wave therapy versus conventional surgery in the treatment of calcifying tendinitis of the shoulder. Clin Orthop Relat Res. 2001 Jun;387:72-82.

**70.** Rebuzzi E, Coletti N, Schiavetti S, Giusto F. Arthroscopy surgery versus shock wave therapy for chronic calcifying tendinitis of the shoulder. J Orthop Traumatol. 2008 Dec;9(4):179-85. Epub 2008 Aug 8.

**71.** Speed CA, Richards C, Nichols D, Burnet S, Wies JT, Humphreys H, Hazleman BL. Extracorporeal shock-wave therapy for tendonitis of the rotator cuff. A double-blind, randomised, controlled trial. J Bone Joint Surg Br. 2002 May;84(4):509-12.

**72.** Engebretsen K, Grotle M, Bautz-Holter E, Ekeberg OM, Juel NG, Brox JI. Supervised exercises compared with radial extracorporeal shock-wave therapy for subacromial shoulder pain: 1-year results of a single-blind randomized controlled trial. Phys Ther. 2011 Jan;91(1):37-47. Epub 2010 Nov 18.

**73.** Zhang JY, Fabricant PD, Ishmael CR, Wang JC, Petrigliano FA, Jones KJ. Utilization of platelet-rich plasma for musculoskeletal injuries: an analysis of current treatment trends in the United States. Orthop J Sports Med. 2016 Dec 21;4(12):2325967116676241.

**74.** Buchbinder R, Johnston RV, Barnsley L, Assendelft WJJ, Bell SN, Smidt N. Surgery for lateral elbow pain. Cochrane Database Syst Rev. 2011 Mar 16;3:CD003525.

**75.** Green S, Buchbinder R, Barnsley L, Hall S, White M, Smidt N, Assendelft W. Acupuncture for lateral elbow pain. Cochrane Database Syst Rev. 2002;1:CD003527.

**76.** Krogh TP, Bartels EM, Ellingsen T, Stengaard-Pedersen K, Buchbinder R, Fredberg U, Bliddal H, Christensen R. Comparative effectiveness of injection therapies in lateral epicondylitis: a systematic review and network meta-analysis of randomized controlled trials. Am J Sports Med. 2013 Jun;41(6):1435-46. Epub 2012 Sep 12.

**77.** Loew LM, Brosseau L, Tugwell P, Wells GA, Welch V, Shea B, Poitras S, De Angelis G, Rahman P. Deep transverse friction massage for treating lateral elbow or lateral knee tendinitis. Cochrane Database Syst Rev. 2014 Nov 8;11:CD003528.

**78.** Silagy M, O'Bryan E, Johnston RV, Buchbinder R. Autologous blood and platelet rich plasma injection therapy for lateral elbow pain. Cochrane Database Syst Rev. 2014;2:CD010951.

**79.** Speed CA, Nichols D, Richards C, Humphreys H, Wies JT, Burnet S, Hazleman BL. Extracorporeal shock wave therapy for lateral epicondylitis—a double blind randomised controlled trial. J Orthop Res. 2002 Sep;20(5):895-8.

**80.** Thiele S, Thiele R, Gerdesmeyer L. Lateral epicondylitis: this is still a main indication for extracorporeal shockwave therapy. Int J Surg. 2015 Dec;24(Pt B):165-70. Epub 2015 Oct 9.

**81.** Sims SE, Miller K, Elfar JC, Hammert WC. Non-surgical treatment of lateral epicondylitis: a systematic review of randomized controlled trials. Hand (N Y). 2014 Dec;9(4):419-46.

**82.** Buchbinder R, Green SE, Youd JM, Assendelft WJ, Barnsley L, Smidt N. Shock wave therapy for lateral elbow pain. Cochrane Database Syst Rev. 2005 Oct 19;4:CD003524.

**83.** Dingemanse R, Randsdorp M, Koes BW, Huisstede BM. Evidence for the effectiveness of electrophysical modalities for treatment of medial and lateral epicondylitis: a systematic review. Br J Sports Med. 2014 Jun;48(12):957-65. Epub 2013 Jan 18.

**84.** Rompe JD, Maffulli N. Repetitive shock wave therapy for lateral elbow tendinopathy (tennis elbow): a systematic and qualitative analysis. Br Med Bull. 2007;83:355-78. Epub 2007 Jul 11.

**85.** Pettrone FA, McCall BR. Extracorporeal shock wave therapy without local anesthesia for chronic lateral epicondylitis. J Bone Joint Surg Am. 2005 Jun;87(6):1297-304.

**86.** Lee SS, Kang S, Park NK, Lee CW, Song HS, Sohn MK, Cho KH, Kim JH. Effectiveness of initial extracorporeal shock wave therapy on the newly diagnosed lateral or medial epicondylitis. Ann Rehabil Med. 2012 Oct;36(5):681-7. Epub 2012 Oct 31.

**87.** Radwan YA, ElSobhi G, Badawy WS, Reda A, Khalid S. Resistant tennis elbow: shock-wave therapy versus percutaneous tenotomy. Int Orthop. 2008 Oct;32(5):671-7. Epub 2007 Jun 6.

**88.** Rompe JD, Segal NA, Cacchio A, Furia JP, Morral A, Maffulli N. Home training, local corticosteroid injection, or radial shock wave therapy for greater trochanter pain syndrome. Am J Sports Med. 2009 Oct;37(10):1981-90. Epub 2009 May 13.

**89.** Furia JP, Rompe JD, Maffulli N. Low-energy extracorporeal shock wave therapy as a treatment for greater trochanteric pain syndrome. Am J Sports Med. 2009 Sep;37(9):1806-13. Epub 2009 May 13.

**90.** Mani-Babu S, Morrissey D, Waugh C, Screen H, Barton C. The effectiveness of extracorporeal shock wave therapy in lower limb tendinopathy: a systematic review. Am J Sports Med. 2015 Mar;43(3):752-61. Epub 2014 May 9.

**91.** Leal C, Ramon S, Furia J, Fernandez A, Romero L, Hernandez-Sierra L. Current concepts of shockwave therapy in chronic patellar tendinopathy. Int J Surg. 2015 Dec;24(Pt B):160-4. Epub 2015 Oct 9.

**92.** Figueroa D, Figueroa F, Calvo R. Patellar tendinopathy: diagnosis and treatment. J Am Acad Orthop Surg. 2016 Dec;24(12):e184-92.

**93.** Gaida JE, Cook J. Treatment options for patellar tendinopathy: critical review. Curr Sports Med Rep. 2011 Sep-Oct;10(5):255-70.

**94.** Larsson ME, Käll I, Nilsson-Helander K. Treatment of patellar tendinopathy—a systematic review of randomized controlled trials. Knee Surg Sports Traumatol Arthrosc. 2012 Aug;20(8):1632-46. Epub 2011 Dec 21.

**95.** Visnes H, Bahr R. The evolution of eccentric training as treatment for patellar tendinopathy (jumper's knee): a critical review of exercise programmes. Br J Sports Med. 2007 Apr;41(4):217-23. Epub 2007 Jan 29.
**96.** Wang CJ, Ko JY, Chan YS, Weng LH, Hsu SL. Extracorporeal shockwave for chronic patellar tendinopathy. Am J Sports Med. 2007 Jun;35(6):972-8. Epub 2007 Feb 16.
**97.** Furia JP, Rompe JD, Cacchio A, Del Buono A, Maffulli N. A single application of low-energy radial extracorporeal shock wave therapy is effective for the management of chronic patellar tendinopathy. Knee Surg Sports Traumatol Arthrosc. 2013 Feb;21 (2):346-50. Epub 2012 May 25.
**98.** Everhart JS, Cole D, Sojka JH, Higgins JD, Magnussen RA, Schmitt LC, Flanigan DC. Treatment options for patellar tendinopathy: a systematic review. Arthroscopy. 2017 Apr;33(4):861-72. Epub 2017 Jan 16.
**99.** Peers KH, Lysens RJJ, Brys P, Bellemans J. Cross-sectional outcome analysis of athletes with chronic patellar tendinopathy treated surgically and by extracorporeal shock wave therapy. Clin J Sport Med. 2003 Mar;13(2):79-83.
**100.** Vulpiani MC, Vetrano M, Savoia V, Di Pangrazio E, Trischitta D, Ferretti A. Jumper's knee treatment with extracorporeal shock wave therapy: a long-term follow-up observational study. J Sports Med Phys Fitness. 2007 Sep;47(3):323-8.
**101.** Zwerver J, Hartgens F, Verhagen E, van der Worp H, van den Akker-Scheek I, Diercks RL. No effect of extracorporeal shockwave therapy on patellar tendinopathy in jumping athletes during the competitive season: a randomized clinical trial. Am J Sports Med. 2011 Jun;39(6):1191-9. Epub 2011 Feb 1.
**102.** Thijs KM, Zwerver J, Backx FJ, Steeneken V, Rayer S, Groenenboom P, Moen MH. Effectiveness of shockwave treatment combined with eccentric training for patellar tendinopathy: a double-blinded randomized study. Clin J Sport Med. 2017 Mar;27(2):89-96.
**103.** Järvinen TA, Kannus P, Maffulli N, Khan KM. Achilles tendon disorders: etiology and epidemiology. Foot Ankle Clin. 2005 Jun;10(2):255-66.
**104.** Alfredson H, Cook J. A treatment algorithm for managing Achilles tendinopathy: new treatment options. Br J Sports Med. 2007 Apr;41(4):211-6. Epub 2007 Feb 20.
**105.** Scott A, Huisman E, Khan K. Conservative treatment of chronic Achilles tendinopathy. CMAJ. 2011 Jul 12;183(10):1159-65. Epub 2011 Jun 13.
**106.** Rowe V, Hemmings S, Barton C, Malliaras P, Maffulli N, Morrissey D. Conservative management of midportion Achilles tendinopathy: a mixed methods study, integrating systematic review and clinical reasoning. Sports Med. 2012 Nov 1;42 (11):941-67.
**107.** Kearney RS, Parsons N, Costa ML. Achilles tendinopathy management: A pilot randomised controlled trial comparing platelet-richplasma injection with an eccentric loading programme. Bone Joint Res. 2013 Oct 17;2(10):227-32.
**108.** Gerdesmeyer L, Mittermayr R, Fuerst M, Al Muderis M, Thiele R, Saxena A, Gollwitzer H. Current evidence of extracorporeal shock wave therapy in chronic Achilles tendinopathy. Int J Surg. 2015 Dec;24(Pt B):154-9. Epub 2015 Aug 29.
**109.** Costa ML, Shepstone L, Donell ST, Thomas TL. Shock wave therapy for chronic Achilles tendon pain: a randomized placebo-controlled trial. Clin Orthop Relat Res. 2005 Nov;440:199-204.
**110.** Rasmussen S, Christensen M, Mathiesen I, Simonson O. Shockwave therapy for chronic Achilles tendinopathy: a double-blind, randomized clinical trial of efficacy. Acta Orthop. 2008 Apr;79(2):249-56.
**111.** Furia JP. High-energy extracorporeal shock wave therapy as a treatment for insertional Achilles tendinopathy. Am J Sports Med. 2006 May;34(5):733-40.
**112.** Furia JP. High-energy extracorporeal shock wave therapy as a treatment for chronic noninsertional Achilles tendinopathy. Am J Sports Med. 2008 Mar;36 (3):502-8. Epub 2007 Nov 15.
**113.** Rompe JD, Furia J, Maffulli N. Eccentric loading compared with shock wave treatment for chronic insertional Achilles tendinopathy. A randomized, controlled trial. J Bone Joint Surg Am. 2008 Jan;90(1):52-61.
**114.** 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 Mar;37(3):463-70. Epub 2008 Dec 15.
**115.** Al-Abbad H, Simon JV. The effectiveness of extracorporeal shock wave therapy on chronic Achilles tendinopathy: a systematic review. Foot Ankle Int. 2013 Jan;34 (1):33-41.
**116.** Kearney R, Costa ML. Insertional Achilles tendinopathy management: a systematic review. Foot Ankle Int. 2010 Aug;31(8):689-94.
**117.** Roche AJ, Calder JD. Achilles tendinopathy: a review of the current concepts of treatment. Bone Joint J. 2013 Oct;95-B(10):1299-307.
**118.** Lemont H, Ammirati KM, Usen N. Plantar fasciitis: a degenerative process (fasciosis) without inflammation. J Am Podiatr Med Assoc. 2003 May-Jun;93(3):234-7.
**119.** Buchbinder R, Ptasznik R, Gordon J, Buchanan J, Prabaharan V, Forbes A. Ultrasound-guided extracorporeal shock wave therapy for plantar fasciitis: a randomized controlled trial. JAMA. 2002 Sep 18;288(11):1364-72.
**120.** Haake M, Buch M, Schoellner C, Goebel F, Vogel M, Mueller I, Hausdorf J, Zamzow K, Schade-Brittinger C, Mueller HH. Extracorporeal shock wave therapy for plantar fasciitis: randomised controlled multicentre trial. BMJ. 2003 Jul 12;327 (7406):75.
**121.** Chuckpaiwong B, Berkson EM, Theodore GH. Extracorporeal shock wave for chronic proximal plantar fasciitis: 225 patients with results and outcome predictors. J Foot Ankle Surg. 2009 Mar-Apr;48(2):148-55. Epub 2009 Jan 9.
**122.** Wang CJ, Wang FS, Yang KD, Weng LH, Ko JY. Long-term results of extracorporeal shockwave treatment for plantar fasciitis. Am J Sports Med. 2006 Apr;34 (4):592-6.
**123.** Gerdesmeyer L, Frey C, Vester J, Maier M, Weil L Jr, Weil L Sr, Russlies M, Stienstra J, Scurran B, Fedder K, Diehl P, Lohrer H, Henne M, Gollwitzer H. 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 Nov;36(11):2100-9. Epub 2008 Oct 1.
**124.** Ibrahim MI, Donatelli RA, Schmitz C, Hellman MA, Buxbaum F. Chronic plantar fasciitis treated with two sessions of radial extracorporeal shock wave therapy. Foot Ankle Int. 2010 May;31(5):391-7.
**125.** Gollwitzer H, Saxena A, DiDomenico LA, Galli L, Bouché RT, Caminear DS, Fullem B, Vester JC, Horn C, Banke IJ, Burgkart R, Gerdesmeyer L. Clinically relevant effectiveness of focused extracorporeal shock wave therapy in the treatment of chronic plantar fasciitis: a randomized, controlled multicenter study. J Bone Joint Surg Am. 2015 May 6;97(9):701-8.
**126.** Ogden JA, Alvarez RG, Levitt RL, Johnson JE, Marlow ME. Electrohydraulic high-energy shock-wave treatment for chronic plantar fasciitis. J Bone Joint Surg Am. 2004 Oct;86(10):2216-28.
**127.** Rompe JD, Furia J, Cacchio A, Schmitz C, Maffulli N. Radial shock wave treatment alone is less efficient than radial shock wave treatment combined with tissue-specific plantar fascia-stretching in patients with chronic plantar heel pain. Int J Surg. 2015 Dec;24(Pt B):135-42. Epub 2015 May 1.
**128.** Aqil A, Siddiqui MRS, Solan M, Redfern DJ, Gulati V, Cobb JP. Extracorporeal shock wave therapy is effective in treating chronic plantar fasciitis: a meta-analysis of RCTs. Clin Orthop Relat Res. 2013 Nov;471(11):3645-52. Epub 2013 Jun 28.
**129.** Chang KV, Chen SY, Chen WS, Tu YK, Chien KL. Comparative effectiveness of focused shock wave therapy of different intensity levels and radial shock wave therapy for treating plantar fasciitis: a systematic review and network meta-analysis. Arch Phys Med Rehabil. 2012 Jul;93(7):1259-68. Epub 2012 Mar 12.
**130.** Dizon JN, Gonzalez-Suarez C, Zamora MT, Gambito ED. Effectiveness of extracorporeal shock wave therapy in chronic plantar fasciitis: a meta-analysis. Am J Phys Med Rehabil. 2013 Jul;92(7):606-20.
**131.** Othman AM, Ragab EM. Endoscopic plantar fasciotomy versus extracorporeal shock wave therapy for treatment of chronic plantar fasciitis. Arch Orthop Trauma Surg. 2010 Nov;130(11):1343-7. Epub 2009 Dec 24.
**132.** Radwan YA, Mansour AM, Badawy WS. Resistant plantar fasciopathy: shock wave versus endoscopic plantar fascial release. Int Orthop. 2012 Oct;36(10):2147-56. Epub 2012 Jul 11.
**133.** Saxena A, Fournier M, Gerdesmeyer L, Gollwitzer H. 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 Jan 21;2(4):312-6.
**134.** Weil LS Jr, Roukis TS, Weil LS, Borrelli AH. Extracorporeal shock wave therapy for the treatment of chronic plantar fasciitis: indications, protocol, intermediate results, and a comparison of results to fasciotomy. J Foot Ankle Surg. 2002 May-Jun;41(3):166-72.
**135.** Thomas JL, Christensen JC, Kravitz SR, Mendicino RW, Schuberth JM, Vanore JV, Weil LS Sr, Zlotoff HJ, Bouché R, Baker J; American College of Foot and Ankle Surgeons Heel Pain Committee. The diagnosis and treatment of heel pain: a clinical practice guideline-revision 2010. J Foot Ankle Surg. 2010 May-Jun;49(3)(Suppl):S1-19.
**136.** Wang FS, Wang CJ, Chen YJ, Chang PR, Huang YT, Sun YC, Huang HC, Yang YJ, Yang KD. Ras induction of superoxide activates ERK-dependent angiogenic transcription factor HIF-1alpha and VEGF-A expression in shock wave-stimulated osteoblasts. J Biol Chem. 2004 Mar 12;279(11):10331-7. Epub 2003 Dec 16.
**137.** Chen YJ, Kuo YR, Yang KD, Wang CJ, Sheen Chen SM, Huang HC, Yang YJ, Yi-Chih S, Wang FS. Activation of extracellular signal-regulated kinase (ERK) and p38 kinase in shock wave-promoted bone formation of segmental defect in rats. Bone. 2004 Mar;34(3):466-77.
**138.** Ha CH, Kim S, Chung J, An SH, Kwon K. Extracorporeal shock wave stimulates expression of the angiogenic genes via mechanosensory complex in endothelial cells: mimetic effect of fluid shear stress in endothelial cells. Int J Cardiol. 2013 Oct 9;168(4):4168-77. Epub 2013 Aug 1.
**139.** Wang CJ, Yang KD, Ko JY, Huang CC, Huang HY, Wang FS. The effects of shockwave on bone healing and systemic concentrations of nitric oxide (NO), TGF-beta1, VEGF and BMP-2 in long bone non-unions. Nitric Oxide. 2009 Jun;20(4):298-303. Epub 2009 Mar 10.
**140.** Gerdesmeyer L, Schaden W, Besch L, Stukenberg M, Doerner L, Muehlhofer H, Toepfer A. Osteogenetic effect of extracorporeal shock waves in human. Int J Surg. 2015 Dec;24(Pt B):115-9. Epub 2015 Oct 9.
**141.** Ingber DE. Cellular mechanotransduction: putting all the pieces together again. FASEB J. 2006 May;20(7):811-27.
**142.** Valchanou VD, Michailov P. High energy shock waves in the treatment of delayed and nonunion of fractures. Int Orthop. 1991;15(3):181-4.

**143.** Beutler S, Regel G, Pape HC, Machtens S, Weinberg AM, Kremeike I, Jonas U, Tscherne H. [Extracorporeal shock wave therapy for delayed union of long bone fractures - preliminary results of a prospective cohort study]. Unfallchirurg. 1999 Nov;102(11):839-47. German.

**144.** Rompe JD, Rosendahl T, Schöllner C, Theis C. High-energy extracorporeal shock wave treatment of nonunions. Clin Orthop Relat Res. 2001 Jun;387:102-11.

**145.** Wang CJ, Chen HS, Chen CE, Yang KD. Treatment of nonunions of long bone fractures with shock waves. Clin Orthop Relat Res. 2001 Jun;387:95-101.

**146.** Schaden W, Fischer A, Sailler A. Extracorporeal shock wave therapy of non-union or delayed osseous union. Clin Orthop Relat Res. 2001 Jun;387:90-4.

**147.** Wang CJ, Liu HC, Fu TH. The effects of extracorporeal shockwave on acute high-energy long bone fractures of the lower extremity. Arch Orthop Trauma Surg. 2007 Feb;127(2):137-42. Epub 2006 Oct 13.

**148.** Bara T, Synder M. Nine-years experience with the use of shock waves for treatment of bone union disturbances. Ortop Traumatol Rehabil. 2007 May-Jun;9(3):254-8.

**149.** Xu ZH, Jiang Q, Chen DY, Xiong J, Shi DQ, Yuan T, Zhu XL. Extracorporeal shock wave treatment in nonunions of long bone fractures. Int Orthop. 2009 Jun;33 (3):789-93. Epub 2008 Apr 25.

**150.** Elster EA, Stojadinovic A, Forsberg J, Shawen S, Andersen RC, Schaden W. Extracorporeal shock wave therapy for nonunion of the tibia. J Orthop Trauma. 2010 Mar;24(3):133-41.

**151.** Zelle BA, Gollwitzer H, Zlowodzki M, Bühren V. Extracorporeal shock wave therapy: current evidence. J Orthop Trauma. 2010 Mar;24(Suppl 1):S66-70.

**152.** Cacchio A, Giordano L, Colafarina O, Rompe JD, Tavernese E, Ioppolo F, Flamini S, Spacca G, Santilli V. Extracorporeal shock-wave therapy compared with surgery for hypertrophic long-bone nonunions. J Bone Joint Surg Am. 2009 Nov;91(11):2589-97.

**153.** Furia JP, Rompe JD, Cacchio A, Maffulli N. Shock wave therapy as a treatment of nonunions, avascular necrosis, and delayed healing of stress fractures. Foot Ankle Clin. 2010 Dec;15(4):651-62.

**154.** Furia JP, Juliano PJ, Wade AM, Schaden W, Mittermayr R. Shock wave therapy compared with intramedullary screw fixation for nonunion of proximal fifth metatarsal metaphyseal-diaphyseal fractures. J Bone Joint Surg Am. 2010 Apr;92(4):846-54.

**155.** Notarnicola A, Moretti L, Tafuri S, Gigliotti S, Russo S, Musci L, Moretti B. Extracorporeal shockwaves versus surgery in the treatment of pseudoarthrosis of the carpal scaphoid. Ultrasound Med Biol. 2010 Aug;36 (8):1306-13.

**156.** Kuo SJ, Su IC, Wang CJ, Ko JY. Extracorporeal shockwave therapy (ESWT) in the treatment of atrophic non-unions of femoral shaft fractures. Int J Surg. 2015 Dec;24(Pt B):131-4. Epub 2015 Jul 9.

**157.** Schaden W, Mittermayr R, Haffner N, Smolen D, Gerdesmeyer L, Wang CJ. Extracorporeal shockwave therapy (ESWT)—first choice treatment of fracture non-unions? Int J Surg. 2015 Dec;24(Pt B):179-83. Epub 2015 Oct 9.

**158.** Lyon R, Liu XC, Kubin M, Schwab J. Does extracorporeal shock wave therapy enhance healing of osteochondritis dissecans of the rabbit knee?: a pilot study. Clin Orthop Relat Res. 2013 Apr;471(4):1159-65.

**159.** Moretti B, Notarnicola A, Moretti L, Giordano P, Patella V. A volleyball player with bilateral knee osteochondritis dissecans treated with extracorporeal shock wave therapy. Chir Organi Mov. 2009 May;93(1):37-41. Epub 2009 Apr 28.

**160.** Thiele S, Thiele R, Gerdesmeyer L. Adult osteochondritis dissecans and focussed ESWT: a successful treatment option. Int J Surg. 2015 Dec;24(Pt B):191-4. Epub 2015 Oct 9.

**161.** Dubs B. Efficacy and economical aspects: comparison ESWT versus alternate therapies in the treatment of calcifying tendinitis. Read at the 6th International Congress of the International Society for Musculoskeletal Shockwave Therapy;; 2003; Orlando, Florida.

**162.** Haake M, Rautmann M, Wirth T. Assessment of the treatment costs of extracorporeal shock wave therapy versus surgical treatment for shoulder diseases. Int J Technol Assess Health Care. 2001 Fall;17(4):612-7.

**163.** Ramón S, Moya D, Alvarez P, Cugat R, Corbella X. Efficiency in treatment of calcifying tendinopathy of the shoulder: extracorporeal shockwave therapy vs. surgery. Read at the 13th International Congress of Shoulder and Elbow Surgery; 2016 May 18-20; Jeju, Korea.

**164.** Wright JG. Revised grades of recommendation for summaries or reviews of orthopaedic surgical studies. J Bone Joint Surg Am. 2006 May;88(5):1161-2.