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Narrative Review

Effect of Shockwave Treatment for Management of Upper and Lower Extremity Musculoskeletal Conditions: A Narrative Review

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Abstract

Extracorporeal shockwave therapy (ESWT) is a technology that was first introduced into clinical practice in 1982 for urologic conditions. Subsequent clinical applications in musculoskeletal conditions have been described in treatment of plantar fasciopathy, both upper and lower extremity tendinopathies, greater trochanteric pain syndrome, medial tibial stress syndrome, management of nonunion fractures, and joint disease including avascular necrosis. The aim of this review is to summarize the current understanding of treatment of musculoskeletal conditions with ESWT, accounting for differences in treatment protocol and energy levels. Complications from ESWT are rare but include 2 reported cases of injury to bone and Achilles tendon rupture in older adults using focused shockwave. Collectively, studies suggest ESWT is generally well-tolerated treatment strategy for multiple musculoskeletal conditions commonly seen in clinical practice.

Level of Evidence: III

Introduction

Extracorporeal shockwave therapy (ESWT) was first introduced into clinical practice in 1982 for urinary stone lithotripsy [1]. This technology revolutionized the approach to nephrolithiasis management, and quickly became adopted as a first-line, noninvasive, and effective method for treatment of urinary stones [2]. Soon thereafter, ESWT was studied in Orthopedics, as it was hypothesized that ESWT could loosen the cement in total hip arthroplasty revisions [3]. Animal studies conducted in the 1980s revealed that not only could shockwaves disturb the bone-cement interface [4] but also found an osteogenic response and improved fracture healing [5]. Although there is continued evidence for the use of ESWT for fracture healing [6], the majority of orthopedic research has focused on ESWT for treatment of upper and lower extremity tendinopathies, fasciopathies, and soft tissue conditions.

Shockwave was first studied in the treatment of plantar fasciitis in 1996 [7]. The application was subsequently studied for upper extremity conditions, including lateral epicondylitis [8,9] and rotator cuff tendinopathy [10], as well as lower extremity conditions, including Achilles tendinopathy [11], patellar tendinopathy [12], hamstring tendinopathy [13], and greater trochanteric pain syndrome (GTPS) [14,15].

Despite the study of ESWT for more than 3 decades, no standardized protocol exists for the treatment of musculoskeletal conditions. Several variables differ between research studies, including energy flux density (EFD), number of impulses, type of wave (focused or radial), device used, number of treatment sessions, days between sessions, area of application, and use of analgesia during application. Additionally, research protocols vary in recommendations for activity restriction after treatment and the adjuvant treatment with physical therapy, eccentric loading, stretching, and use of nonsteroidal anti-inflammatory drugs (NSAIDs). There is also variation in the definition of conservative treatment, the outcome measures, and length of follow-up among studies. Pain is the primary endpoint for most investigations, with few other outcome measures reported.

The clinical application of ESWT has been a controversial issue in the past, because of the mixed results in research studies. However, there is a mounting body of

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literature that appears to suggest that ESWT may be effective in treating a subset of chronic tendon and plantar fascia diseases for a subset of patients [16]. The purpose of this review is to synthesize the current available research on the use of ESWT for management of upper and lower extremity musculoskeletal conditions and identify best evidence for treatment.

Physiology of Extracorporeal Shockwave Therapy

Shockwaves are sound waves that have certain physical characteristics, including nonlinearity, high peak pressure followed by low tensile amplitude, short rise time, and short duration (10 μs). These characteristics generate a positive and negative phase of shockwave. The positive phase produces direct mechanical forces, whereas the negative phase generates cavitation and gas bubbles that subsequently implode at high speeds, generating a second wave of shockwaves [17]. When compared to ultrasound waves, the shockwave peak pressure is approximately 1000 times greater than the peak pressure of an ultrasound wave [16].

Focused shockwave therapy and radial shockwave therapy are 2 types of shockwave therapy used in clinical practice. Focused shockwaves are generated by electrohydraulic, electromagnetic, and piezoelectric devices. Radial shockwaves are typically produced by pneumatic/ballistic devices [17]. Much of the early research in ESWT for musculoskeletal conditions utilized focused shockwave therapy [17]. Focused shockwaves have higher energy and generate maximal force at a selected depth, whereas radial shockwaves are lower energy and generate highest pressure at the skin surface with subsequent weakening at greater depth [18].

Ioppolo defined *energy flux density* as the energy per impulse at the focal point of the shockwave [19]. In a study by Rompe et al in 1998, the authors classified high EFD as 0.6 mJ/mm^2, medium as 0.28 mJ/mm^2, and low as 0.08 mJ/mm^2 [20]. In this study, the high energy flux application to tendon in an animal model led to persistent histopathologic changes, including inflammation, necrosis, and disorganized fibrocysts. Based on these findings, the authors suggested energy levels exceeding 0.28 mJ/mm^2 may not be appropriate for clinical use in tendon disorders [20].

Mechanism of Action/Theoretical Application in Humans

The effects of ESWT treatment are unknown. Proposed mechanisms of action for ESWT include promoting neovascularization at the tendon-bone junction [21], stimulating proliferation of tenocytes [22] and osteoprogenitor differentiation [23], increasing leukocyte infiltration [20], and amplifying growth factor and protein synthesis to stimulate collagen synthesis and tissue remodeling [22-25]. ESWT may reduce pain through hyperstimulation of nociceptors/gate-control theory of pain transmission, altered pain receptor neurotransmission, and by increasing local pain-inhibiting substances [26-29]. Stimulation of nociceptive C-fibers may not only play a role in analgesia, but also in tendon remodeling, as it may increase release of neuropeptides, causing fibroblast stimulation and vasodilation [30]. A list of additional proposed mechanisms of action of ESWT is included in Table 1 [31,32].

Methodology of Review

The conditions treated are divided into disease states. The primary articles were identified using PubMed search in September 2017 using a combination of the following search terms: *shock wave therapy*, *ESWT*, *extracorporeal shockwave therapy*, *tendinopathy*, and *fasciopathy*. The primary articles were used to identify additional articles by cross-reference. Because of limited total articles identified, we included both retrospective and prospective studies and noted whether studies included a control group, were blinded, and use of placebo. Additionally, the primary and secondary outcome measures for each study were reported.

Studies were each scored by 2 observers using Physiotherapy Evidence Database scale (PEDro) criterion to determine study quality [33]. A score that meets 7 of the 11 criteria has been described as high quality and externally valid in prior meta-analysis using this criterion [34]. All studies scored $\geq$7 with the exception of one study that scored 6 [35]. To quantify the type of shockwave treatment, study design, and protocol, studies included are listed in Tables 2-10 [36,37].

Subject Populations

Many of the studied musculoskeletal conditions are self-limiting diseases. As a result, most studies enrolled patients who had failed multiple conservative treatment options and were considered to have recalcitrant disease processes. Exclusion criteria in subjects often included local arthritis, generalized polyarthritis, rheumatoid arthritis, ankylosing spondylitis, reactive arthritis, nerve entrapments, prior surgeries at the site, pregnancy, infections, tumors, or use of systemic anticoagulation.

Lower Extremity Pathology

Plantar Fasciitis

Shockwave therapy has been studied in the treatment of plantar fasciitis since 1996, with favorable results initially reported in treatment of patients with plantar calcaneal spurs [7]. One early study demonstrating efficacy was a randomized controlled trial (RCT) by Kudo et al that examined 114 patients with a history

Table 1
Proposed mechanisms of action for shockwave

Neovascularization at tendon-bone junction	Wang 2002, Wang 2003
Destruction of calcifications	Peters 2004
Increased collagen synthesis/tissue remodeling	Bosch 2007, Vetrano 2011
Leukocyte infiltration	Rompe 1998
Proliferation of tenocytes	Chen 2004
Increased glycosaminoglycan, increased protein synthesis	Bosch 2007
Increased IL-6, IL-8, MMP-2, MMP-9, increased collagen synthesis	Waugh 2015
Increased TGF-β1 and IGF-1, increased collagen synthesis	Wang 2002, Chen 2004
Mechanotransduction, increased collagen synthesis	Bosch 2007
Increased osteoprogenitor differentiation	Wang 2002
Stimulation of nociceptive C-fibers and resulting neuropeptide release	Klonschinski 2011
Nociceptor hyperstimulation/Gate-control theory	Saggini 2015, Wess 2008, Vahdatpour 2013, Zimmerman 2008
Increase in local pain-inhibiting substances	Saggini 2015, Wess 2008, Vahdatpour 2013, Zimmerman 2008
Impaired cell membrane receptor potential	Wess 2008

IL = interleukin; MMP = matrix metalloproteinase; TGF-β1 = transforming growth factor—beta 1; IGF-1 = insulin-like growth factor 1.

of plantar fasciitis for 6 months or greater [36]. Investigators randomized patients to an active treatment group that would receive a single treatment session of ESWT or placebo. All patients were administered a medial calcaneal nerve block prior to ESWT or sham treatment. The ESWT flux density was incrementally increased to a "high-energy" density. At the 3-month endpoint, the ESWT population was found to have a statistically significant improvement in visual analog scale (VAS) pain scores and Roles-Maudsley scores as compared to the placebo group [36].

Gollwitzer et al studied 246 patients with chronic plantar fasciitis [37]. Subjects were randomized to receive sham or ESWT at weekly intervals for 3 total sessions. The total EFD was uptitrated to 0.25 mJ/mm^2 with 500 introductory impulses, and thereafter treated with that energy for 2000 treatment impulses. Primary outcomes for treatment success included (A) percentage change in heel pain composite VAS score: composed of pain with first morning steps, pain during daily activities, and pain while applying standardized pressure, and (B) improvement in Roles-Maudsley score. At 12 weeks, the success rate of ESWT for pain reduction was 54.4% compared to 37.2% for the placebo group ($P = .0035$, OR 2.015, number needed to treat 5.8) [37].

Rompe et al conducted a randomized, single-blind study in 2015 in which patients were randomized to receive either 3 weekly sessions of low-energy radial shockwave, or combined treatment with ESWT and 8 weeks of a plantar fascia stretching program [38]. All patients received 2000 pulses with an EFD of 0.16 mJ/mm^2, applied to the area of maximal tenderness. After receiving instructions and supervision, patients in the stretching group were asked to perform stretching exercises 3 times daily, for 8 weeks. Eight weeks after baseline assessment, both groups were observed to have improvements in pain; however, subjects instructed to stretch were noted to have greater improvement over those receiving ESWT as monotherapy. The outcomes in the stretching group remained improved up to 4 months, then became similar to those of the non-stretching group at 24 months [38].

Three randomized-control trials did not demonstrate efficacy of ESWT over other treatments for management of chronic plantar fasciitis [39-41]. These 3 studies have been criticized because of methodology issues in treatment protocols [42]. Gollwitzer [37] reported favorable results for treatment of plantar fasciitis in a large RCT, and suggested use of local anesthesia (Haake), lower energy levels (Speed), and anatomical landmarks rather than palpation guidance to direct treatment (Buchbinder) as potential issues in the protocols of the 3 RCTs. The use of local anesthesia prior to ESWT has been found to reduce the efficacy of treatment [43]. Compared to the Kudo study that reported a favorable response to ESWT with multiple treatments [36], the active treatment group in the Speed study received a lower energy treatment (1500 pulses at 0.12 mJ/mm^2) or sham treatment for 3 total sessions administered on a monthly basis. The primary outcome was measured at 3 months following completion of treatment, with a positive response graded as a 50% improvement in VAS score. Seventeen (37%) patients in the active treatment group reported 50% improvement at 3 months, as compared to 10 (24%) of the sham treatment group ($P = .248$, relative risk = 0.827, 95% confidence interval [CI] 0.626-1.093) [40].

Three meta-analyses were performed to evaluate the clinical response of plantar fasciitis to ESWT, each measuring different clinical outcomes. In 2005, Thomson et al [44] performed a meta-analysis examining 11 RCTs published between 1996-2003, including the 3 RCTs that did not demonstrate efficacy [39-41]. Two of the 11 trials did not require the patients to have had symptoms for greater than 6 months, and 3 of the trials used a low dose of ESWT as the control treatment. Outcome measures were obtained at 12 weeks post-treatment in all but 1 trial, which obtained outcome measures at 19 weeks. The pooled analysis from 6 trials

Table 2
Upper extremity studies characterizing effects of shockwave on management by condition: Lateral epicondylitis

Author	Study Design	No. of Subjects	Subject Population*	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions/ Interval
Haake 2002	RCT	271	Not specified	6 mo	Various devices, unspecified	Unspecified	2000 pulses	ED + 0.07-0.09 mJ/mm^2	3; weekly
Speed 2002	RCT	75	Not specified	3 mo	Sonocur Plus	FSWT	1500 pulses	0.18 mJ/mm^2, placebo—placebo 0.04 mJ/mm^2	3; monthly
Melikyan 2003	RCT	74	Not specified on waiting list for surgery	Not specified	Dornier Epos Ultra	FSWT	Variable	333 mJ/mm^2 each session, 1000 mJ/mm^2 total	3; unclear
Rompe 2004	RCT	78	Recreational tennis players	12 mo, not responsive to 3 conservative therapies	Sonocur Plus	FSWT	2000 pulses/ 4 Hz	0.09 mJ/mm^2, total dose 0.54 mJ/mm^2	3; weekly
Chung 2004	RCT	60	Not specified	3 wk—1 y maximum	Sonocur Basic	FSWT	2000 pulses	0.03-0.17 mJ/mm^2, placebo 0.03 mJ/mm^2	3; weekly
Pettrone 2005	RCT	114	Not specified	6 mo, resistant to 2/3 conventional therapies	Sonocur (unspecified)	FSWT	2000 pulses	0.06 mJ/mm^2	3; weekly
Staples 2008	RCT	68	Not specified	6 wk	Dornier MedTech Epos	FSWT	Treatment: 2000 pulses/wk, energy as tolerated by patient. Placebo: 100 shocks/wk, 4 Hz	Variable-Median total dose 1062 mJ/mm^2, placebo total dose 6 mJ/mm^2	3; weekly

EFD = energy flux density; RCT = randomized controlled trial; ED+ = positive energy flux density; FSWT = focused shockwave therapy; VAS = visual analog scale; UEFS = Upper Extremity Functional Scale; ESWT = extracorporeal shockwave therapy; UE = upper extremity; EQ5D = EuroQol 5D; NSAID = nonsteroidal anti-inflammatory drug; ADLs = activities of daily living; DASH = Disabilities of the Arm, Shoulder, and Hand; QoL = quality of life; SF-36 = 36-Item Short Form Health Survey.
* The designation "not specified" was applied to studies that did not specify level of physical activity or sport of the population treated.

revealed a statistically significant but small treatment effect ($P = .04$, 95% CI 0.02-0.83). The resulting reduced pain equated to a change on a 10-cm VAS, of less than a half-centimeter [44].

In 2013, Dizon et al [34] performed a meta-analysis of 11 RCTs published between 1990-2010, all in subjects with heel pain for longer than 6 months. The studies were classified as using low-intensity (<0.1 mJ/mm^2), moderate intensity (0.1-0.2 mJ/mm^2), and high-intensity shockwave (>0.2 mJ/mm^2). This review also included the RCTs by Haake, Buchbinder, and Speed [39-41]. The authors found that there was no difference in decreasing overall pain; however, a subgroup analysis revealed that moderate-intensity ESWT was effective in

Table 2
Continued

Local Anesthesia	Area Applied	Adjuvant Treatment	Follow-up	Primary Outcomes	Secondary Outcomes	Results
Yes	Landmark, ultrasound guidance	Not specified	6, 12 wk, 12 mo	Roles-Maudsley (RM) score 1 or 2, and no additional treatment	Roles-Maudsley Scores, Pain on 11-point scale, grip strength	No significant difference at time points
No	Ultrasound guidance, maximal tenderness	Not specified	1, 2, 3 mo from baseline (1 mo after completion)	50% improvement from baseline at 3 mo in day pain or night pain on VAS	Not specified	No significant difference in pain between groups
Not specified	Landmark, ultrasound guidance	Not specified. No restrictions on activities.	1, 3, 12 mo after last treatment	Surgery or removal from waiting list	DASH function/ symptom score, pain on VAS, grip strength, analgesic requirement	No significant difference between placebo and control at any time point, in any outcomes. 46% of treatment group patients underwent surgery, 43% in the control group
No	Maximal tenderness/ clinical focusing technique	Could use pretreatment splint/braces, but no other treatments until the 3-mo follow-up. No pain medications	3, 12 mo post-treatment	Reduction in pain on VAS at 3 mo on Thomsen Test, >30% decrease in .pain on VAS	Pain reduction on VAS, Roles-Maudsley Score, UEFS, grip strength, overall satisfaction	At 3 mo, statistically significant difference in pain on VAS, RM score, UEFS, Satisfaction. No difference in grip strength. At 12 mo, 71% of ESWT patients returned to playing, 55% of placebo group, $P = .165$
Not specified	Maximal Tenderness	Forearm stretching program	4, 8 wk after initiation of therapy	Treatment success: >50% reduction in overall pain on VAS, maximum allowable overall pain of 4 on VAS, No use of pain med for elbow pain for 2 wk before the 8-wk follow-up	Pain on VAS— overall, rest, during sleep, during activity, pain at worst, pain at least, pain with activity, QoL on EQ5D, pain-free maximum grip strength	No significant difference between groups in treatment success.
No	Maximal tenderness/ clinical focusing technique	Not specified	1, 4, 8, 12 wk, 6, 12 mo after completion	Improved pain with Thomsen test on VAS at 12 wk	Pain on Thomsen testing, Functional scale, Activity score, grip strength, subjective evaluation (patient)	Statistically significant improvement in pain, UE function, and activity between treatment groups at 12 wk. Grip strength improved but not significantly.
Not specified	Ultrasound guidance, maximal tenderness	Instructed in standard stretching, could wear braces/splints, instructed to hold NSAIDs 2 wk prior to study. No other interventions during first 6 wk.	6 wk, 3, 6 mo after completion of treatment	Pain on VAS, Function on VAS, Discomfort in ADLs, DASH, QoL on SF-36, Health Status Questionnaire, maximum pain-free grip strength/ maximum grip strength on dynamometer, problem elicitation technique	Not specified	No significant differences in outcomes between ESWT and placebo, except in 3-mo DASH (favored treatment group)

decreasing overall pain ($P < .00001$) and activity pain ($P = .001$). ESWT was also found to be effective in decreasing morning pain ($P = .004$) and increasing functional outcome ($P = .0001$). The study data suggest that moderate- and high-intensity ESWT were superior to low-intensity ESWT in management of chronic plantar fasciitis [34].

Lou et al [45] conducted a meta-analysis in 2017 that examined 9 RCTs published between 2001 and 2015. The investigators reported that in patients with chronic plantar fasciitis, 40.5%-60% had reduction in heel pain, 41.3%-60.8% had improvement in morning heel pain, and 49.6%-60% had improvement in heel pain during daily activities [45].

Table 3
Upper extremity studies characterizing effects of shockwave on management by condition: Rotator cuff tendonitis

Author	Study Design	No. of Subjects	Subject Population*	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions; Interval	Local Anesthesia
Speed 2002	RCT	74	Not specified	3 mo	Sonocur Plus	FSWT	1500 pulses	0.12 mL/mm^2	3; monthly	No
Ioppolo 2012	RCT	46	Not specified	4 mo	Modulith SLK	FSWT	2400 pulses	0.20 or 0.10 mJ/mm^2	4; weekly	No, patients took NSAID 1 h prior to treatment
Galasso 2012	RCT	20	Not specified	4 mo	Modulith SLK	FSWT	3000 pulses	0.068 mJ/mm^2	2; weekly	Yes
Li 2017	RCT	84	Not specified	6 mo	Sonothera	RSWT	3000 pulses	0.11 mJ/mm^2, 3 bar	5; 3 d	Not specified

EFD = energy flux density; RCT = randomized controlled trial; FSWT = focused shockwave therapy; RSWT = radial shockwave therapy; SPADI = Shoulder Pain and Disability Index; NSAID = nonsteroidal anti-inflammatory drug; CMS = Constant-Murley Score; VAS = visual analog scale; NRS = numeric rating scale; ROM = range of motion; SST = Simple Shoulder Test; ESWT = extracorporeal shockwave therapy.
* The designation "not specified" was applied to studies that did not specify level of physical activity or sport of the population treated.

Achilles tendinopathy

Several studies have been conducted to evaluate the effectiveness of ESWT in treating Achilles tendinopathy. An initial study using focused ESWT delivered once monthly for 3 sessions did not detect differences in outcome [46]. Subsequent studies providing treatment on a weekly basis demonstrated favorable results. Rasmussen et al [47] assessed 48 patients with Achilles tendinopathy for greater than 12 weeks and randomized them to treatment with stretching and eccentric exercises and sham ESWT or ESWT. The intervention group received 4 weekly sessions of 2000 pulses (0.12-0.51 mJ/mm^2) radial shock waves. The primary outcomes measured included VAS for pain and American Orthopaedic Foot and Ankle Society Score (AOFAS). The patients were followed at intervals of 4, 8, and 12 weeks. Investigators reported a statistically significant increase in the AOFAS score of the intervention group, with best results measured at 8 and 12 weeks. Both groups reported reduced pain; however, these differences were not statistically significant.

Rompe conducted 2 studies assigning eccentric loading for the control group. For insertional Achilles tendinopathy, the control group was assigned the Alfredson protocol and compared to ESWT monotherapy. Superior pain relief and functional outcome with Victorian Institute of Sports Assessment (VISA-A) was measured for the ESWT group [48], although the eccentric group did have improvement in symptoms. Notably, the eccentric loading program did not use the modified Alfredson protocol as it had not yet been described at the time of the study [49]. Additionally, the presence of a Haglund's deformity has been found to be associated with reduced outcome success for those treated with insertional Achilles tendinopathy [50]. In a separate study, Rompe et al [51] compared subjects with midportion Achilles tendinopathy randomized to ESWT plus eccentric loading to subjects who were assigned eccentric loading. ESWT combined with eccentric loading was found to yield greater improvement in pain and function as compared to eccentric loading alone at 4 months, though the groups had similar outcomes at a 1-year follow-up [51].

In 2015, a systematic review was conducted on 11 studies evaluating the use of ESWT for Achilles tendinopathy. The authors concluded that ESWT demonstrated best evidence for short-term pain reduction and improved function compared to nonoperative treatment [52]. Of the studies included, 1 RCT found no difference between treatment arms [46]; however, the authors of the review note that the subject population had an average age that was 10 years older on average for the ESWT group compared to the conservative group, and that this may have affected outcomes [52].

Patellar Tendinopathy

In 2007, Vulpiani et al [12] performed a prospective study in 73 patients with patellar tendinopathy, consisting of treatment with an average of 4 weekly sessions of 1,500-2,500 impulses with energy varying from 0.08-0.44 mJ/mm^2 adjusted to pain tolerance. At the 1-month follow-up interval, 43.4% were found to benefit, 63.9% at 6-12 months, 68.8% at 13-24 months, and finally 79.7% at >24 months as defined by a scale created by the authors incorporating both improvement in pain on VAS and clinical improvement [12].

Zwerver et al [53] conducted an RCT to assess the efficacy of ESWT in treating patellar tendinopathy in athletes who were actively competing, and found no benefit in this population with symptom duration less than 12 months. The patients received 3 weekly sessions of 2000 impulses with an EFD uptitrated to a maximum possible level of 0.58 mJ/mm^2. The control group received the same treatment, with the exception that

Table 3
Continued

Area Applied	Adjuvant Treatment	Follow-up	Primary Outcomes	Secondary Outcomes	Results
Ultrasound guidance, maximal tenderness	None	1, 2, 3, and 6 mo	>50% reduction in pain	SPADI, night pain	No significant difference between groups
Not specified	Not mentioned	3, 6, 12 mo after intervention	Change in CMS at 3 and 6 mo	Pain on VAS, radiographic size of calcium deposits, Pain on NRS	At 6 mo, higher-energy group had significant improvement over lower-energy group in VAS scores and CMS, and quicker improvement
Landmark, ultrasound guidance	No pain medications 3 d prior to CMS evaluation	6, 12 wk	Improvement of >30 points or CMS >80% standard at follow-up	CMS, physical exam	At 3 mo, mean relative improvement in total CMS, CMS pain, and ROM was significantly improved in treatment group compared to control
Not specified	Not specified	4, 8 wk after treatment	Pain on NRS	CMS, SST, adverse events	ESWT significantly improved pain and shoulder function at both time points

no applicator gel was placed. The primary outcome, as measured by the Victorian Institute of Sport Assessment—Patella (VISA-P) score, improved in both the control and treatment groups, and no significant difference between the groups was found at 1, 12, and 22 weeks. As opposed to the treatment protocol by Vulpiani, these athletes continued to participate in sport at their usual level without limitations on training. The authors suggest that ESWT is more effective in treating chronic patellar tendinopathy as opposed to the early stages of the disease process; however, they did not combine ESWT with standard conservative treatment, including eccentric loading. Additionally, the ESWT subjects were treated with energy levels exceeding the threshold that has been documented to contribute to tendon damage in animal model investigation [20].

In 2015, Mani-Babu et al [52] conducted a systematic review to evaluate the effectiveness of ESWT in treating patellar tendinopathy. The review included 5 studies consisting of 2 RCTs, 2 prospective trials and 1 retrospective trial. Overall, the results largely supported ESWT as a promising option for both short- and long-term treatment success [52]. A recent systematic review analyzed both surgical and nonsurgical treatment options available for treating patellar tendinopathy [54]. The authors concluded that treatment with ESWT should be considered following 6 months of nonsurgical treatment with eccentric exercises and physical therapy; however, ESWT may be considered for patients who are no longer progressing in physical therapy or those who do not want/or are determined to be poor surgical candidates [54].

Hamstring Tendinopathy

One published study to date has been conducted in ESWT for high hamstring tendinopathy and demonstrated favorable results. Cacchio et al [13] evaluated 40 patients with MRI-verified chronic proximal hamstring tendinopathy and randomized (N=20 each group) each to ESWT or conservative treatment. Shockwaves were administered for 4 sessions at weekly intervals, of 2500 shocks with EFD of 0.18 mJ/mm^2. The traditional conservative treatment group was treated with NSAIDs, followed by physical therapy, and finally an exercise program for a total of 6 weeks. The primary outcomes were a 3-point decrease on VAS score and a 2-phase decrease in the Nirschl phase rating scale evaluated at 1 week, 6 months, and 12 months after treatment. A larger reduction in both outcomes measures was observed at all time points for ESWT over conservative care. Of clinical relevance, 80% of the ESWT group could return to their pre-injury level of sport, as opposed to zero of the patients from conservative care. No major complications were reported in the ESWT group.

Greater Trochanteric Pain Syndrome (GTPS)

Furia et al [14] published a retrospective cohort study in 2009 examining 33 patients diagnosed with GTPS and symptoms for an average duration of 13.7 months. Each patient received a single session of 2000 shocks at 0.18 mJ/mm^2. The primary outcome was measured using VAS scores, Harris Hip Scores, and Roles-Maudsley scores at 1, 3, and 12 months post-treatment. At each interval, subjects reported a statistically significant improvement in all outcome measures [14].

Rompe et al [15] compared ESWT to corticosteroid injections and a home training program in patients with GTPS. Although a single palpation-guided corticosteroid injection targeting the greater trochanteric bursa and other painful regions yielded significantly better pain control at 1 month after intervention compared with ESWT and home training program, ESWT produced significantly better results at 4 months and 15 months after intervention [15].

Table 4
Lower extremity studies characterizing effects of shockwave on management by condition: Plantar fasciitis

Author	Study Design	No. of Subjects	Subject Population*	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions; Interval	Local Anesthesia	Area Applied
Rompe 1996	Prospective Cohort	30	Not specified	12 mo	Siemens Osteostar	FSWT	1000 pulses	0.06 mJ/mm^2	3; weekly	Not specified	Landmark, fluoroscopy—at heel spur and 3 points around
Buchbinder 2002	RCT	166	Not specified	6 wk	Dornier Epos Ultra	FSWT	2000-2500 pulses	0.02-0.33 mJ/mm^2	3; weekly	Not specified	Landmark, ultrasound guidance
Haake 2003	RCT	272	Not specified	6 mo	Dornier Epos Ultra	FSWT	4000 pulses	0.08 mJ/mm^2 EFD+	3; 2 wk	Yes	Landmark, ultrasound guidance
Speed 2003	RCT	88	Not specified	3 mo	Sonocur Plus Siemens	FSWT	1500 pulses	0.12 mJ/mm^2	3; monthly	No	Ultrasound guidance, maximal tenderness
Rompe 2005	RCT	86	Not specified	6 mo	Sonocur Siemens	FSWT	2000 pulses, 4 Hz	0.09 mJ/mm^2	3; weekly	With and without anesthesia	Ultrasound guidance, maximal tenderness
Kudo 2006	RCT	114	Not specified	6 mo	Dornier Epos Ultra	FSWT	3800 ± 10 pulses, variable frequency	Variable, Total 2330 mJ/mm^2	1	Medical calcaneal nerve block	Maximal tenderness
Gollwitzer 2015	RCT	246	Not specified	6 mo, failed nonsurgical treatment modalities	Duolith SD1	FSWT	500 introductory pulses, followed by 2000 pulses, 4 Hz	0.25 mJ/mm^2	3; weekly	Per participant request	Maximal tenderness
Rompe 2015	RCT	152	Not specified	12 mo, failed 3 other forms treatment	EMS Electro-Medical Systems	RSWT	2000 pulses, 8 Hz	Total EFD 320 mJ/mm^2/ treatment, 0.16 mJ/ mm^2 +EFD	3; weekly	No	Maximal tenderness

EFD = energy flux density; RCT = randomized controlled trial; FSWT = focused shockwave therapy; RSWT = radial shockwave therapy; VAS = visual analog scale; SF-36 = 36-Item Short Form Health Survey; ESWT = extracorporeal shockwave therapy; RM = Roles-Maudsley; NRS = numeric rating scale; AOFAS = American Orthopaedic Foot and Ankle Score; LA = local anesthesia; SF-12 = 12-Item Short Form Health Survey.
* The designation "not specified" was applied to studies that did not specify level of physical activity or sport of the population treated.

Medial Tibial Stress Syndrome

Rompe et al [55] conducted a case-control study consisting of patients with medial tibial stress syndrome (MTSS) who were offered treatment with radial ESWT. All patients had symptoms for longer than 6 months and had imaging to exclude fracture. After being explained the side effects and cost, 49 of 127 subjects chose treatment with radial shockwave and a home training program, and of the remaining 78 subjects who chose the home training program alone, 47 were selected as controls by a blinded medical assistant. Each shockwave subject received 3 weekly low-energy treatments (EFD 0.1 mJ/mm^2, total EFD 200 mJ/mm^2). The severity of

Table 4
Continued

Adjuvant Treatment	Follow-up	Primary Outcome Measures	Secondary Outcome Measures	Results
No other treatments/drugs 6 wk before or during ESWT	3, 6, 12, 24 wk after last application	Night pain, resting pain, pressure pain on VAS	Pain-free plantar pressure, walking ability without need to rest	Significant improvement in pain and function at all follow-ups in treatment group
Allowed to continue prior orthotics/splints, no other treatment	6 and 12 wk after completion	Overall pain on VAS at 12 wk	VAS pain—overall, morning, activity; walking ability without need to rest; Maryland Foot Score; Problem Elicitation Technique (PET); SF-36; success of blinding	No significant benefit in ESWT group as compared to control in all outcomes
No additional treatment prior to 12 wk, after 12 wk able to receive other treatment	6, 12 wk, 1 y after last treatment	RM score at 12 wk post-treatment, Success defined as RM score of 1 or 2 and if patient received no additional treatment at 12 wk	Pain on NRS, walking ability, need for additional treatments for 1 y after last intervention	Comparable improvement between groups, no statistically significant difference
No other treatments allowed	1, 4 mo from baseline (1 mo after completion)	Positive response, 50% improvement VAS foot pain during day and night, start-up pain	None	No significant benefit in ESWT group as compared to control in all outcomes
No other treatments/ medications during treatment/follow-up. Pain rescue medication allowed	3 wk, 3, 12 mo after last application	Reduction in pain at 3 mo on NRS for pain during first steps	Number of patients with >50% improvement in pain NRS during first steps, number of patients >80 patients on AOFAS, number of patients with >50% improvement on subjective 4-point rating scale	Significantly improved NRS in ESWT without LA as compared to ESWT and LA ($P < .001$)
Not specified	3-5 d, 6 wk, 3 mo post-treatment. 6, 12 mo in ESWT group	Pain with first few minutes of walking on VAS at 3 mo	Change in AOFAS, RM score, SF12, pain on palpation, Clinical success as defined by >60% pain reduction	Significant improvement in morning pain first steps $P < .0001$ in active compared to placebo, 25/43 (47%) in ESWT and 12/52 (23%) placebo met clinical success ($P = .0099$). Significant improvement in RM score $P = .0121$, pain on palpation ($P = .0027$)
No other therapies. Could use 2 g acetaminophen/d during study up to 14 d after last intervention, then could use 2 g/wk	12 wk, 12 mo	Percentage change composite VAS heel pain, RM score at 12 wk post-treatment, pressure pain tolerance on VAS	Subjective effectiveness as graded by investigator, rates of success: >60% pain reduction in single VAS, overall success >60% pain reduction in 2/3 VAS measurements, RM success: excellent or good, analgesic requirement, patient satisfaction	ESWT significantly more effective at reducing heel pain on median composite score VAS ($P = .0027$), and improving RM score ($P = .0006$). Patient satisfaction, heel pain overall success rate, investigator effectiveness, and single VAS success rate for heel pain were significantly improved in the ESWT group. At 12 mo follow-up, treatment success persisted
Asked to not partake in PT, received heel pads. Could take NSAID if necessary. Asked to return to recreational activity at 4 wk. Treatment group received instructions on plantar-fascia stretching program.	2, 4, 24 mo after baseline	Mean change in Foot Function Index score at 8 wk, pain during first morning steps, satisfaction with treatment on patient relevant outcome measure	Not specified	ESWT and stretching yielded significantly improved scores on Foot Function Index ($P < .001$), morning pain ($P < .001$), and patient satisfaction ($P < .001$) at 2 mo. Differences remained significant at 4 mo, not at 24 mo

pain as measured by a numeric rating scale was found to be significantly improved in the ESWT cohort at 1, 4, and 15 months. Fifteen months after treatment, 40 of the 47 patients in the ESWT group were able to return to their sport. In contrast, 22 of the 47 in the control group returned to sport. Additionally, patients in the ESWT group were more likely to state that they felt "completely recovered" or "much improved" at all 3 time points.

In 2012, Moen et al [35] conducted a prospective control study of athletes with MTSS who were treated with either a running program or focused shockwave in combination with a running program. Five focused shockwave sessions were performed at weeks 1, 2, 3, 5,

Table 5
Lower extremity studies characterizing effects of shockwave on management by condition: Achilles tendinopathy

Author	Study Design	No. of Subjects	Subject Population*	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions; Interval	Local Anesthesia
Costa 2005	RCT	49	Not specified	4 mo	Storz Modulith SLK	FSWT	1500 pulses	Max 0.2 mJ/mm^2	3; monthly	No
Rasmussen 2008	RCT	48	Not specified	3 mo	Piezoson 100	FSWT	2000 pulses, 50 Hz	0.12-0.51 mJ/mm^2, placebo: 0 mJ/mm^2	4; weekly	No
Rompe 2008	RCT	50	Not specified	6 mo	EMS Swiss Dolorclast	RSWT	2000 pulses, 8 Hz	0.12 mJ/mm^2, 2.5 bar	3; weekly	No
Rompe 2009	RCT	68	Not specified	6 mo	EMS Swiss Dolorclast	RSWT	2000 pulses, 8 Hz	0.1 mJ/mm^2	3; weekly	No
Wu 2016	Retrospective cohort	67	Not specified	6 mo	EMS Swiss Dolorclast	RSWT	2000 pulses, 8 Hz	0.12 mJ/mm^2	5; weekly	No

EFD = energy flux density; RCT = randomized controlled trial; FSWT = focused shockwave therapy; RSWT = radial shockwave therapy; VAS = visual analog scale; ROM = range of motion; FIL = Functional Index of Lower Limb Activity; EQoL = EuroQol Generalized Health Status Questionnaire; AOFAS = American Orthopaedic Foot and Ankle Score; ESWT = extracorporeal shockwave therapy; NSAIDs = nonsteroidal anti-inflammatory drugs; VISA-A = Victorian Institute of Sports Assessment-Achilles tendinopathy; NRS = numeric rating scale.
* The designation "not specified" was applied to studies that did not specify level of physical activity or sport of the population treated.

Table 6
Lower extremity studies characterizing effects of shockwave on management by condition: Patellar tendinopathy

Author	Study Design	No. of Subjects	Subject Population	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions; Interval	Local Anesthesia
Vulpiani 2007	Prospective cohort	73	Athletes: 13 professional, 41 amateur, 19 weekly	3 mo	Storz Medical	FSWT	1500-2500 pulses	0.08-0.44 mJ/mm^2	Average 4; 2-7 d	No
Zwerver 2011	RCT	62	Athletes	3-12 mo	Piezowave	FSWT	2000 pulses, 4 Hz	Variable, maximum 0.58 mJ/mm^2	3; weekly	No

EFD = energy flux density; FSWT = focused shockwave therapy; RCT = randomized controlled trial; VAS = visual analog scale; VISA-P = Victorian Institute of Sport Assessment Questionnaire, Patellar Tendon; VAS = visual analog scale; ADLs = activities of daily living.

Table 5
Continued

Area Applied	Adjuvant Treatment	Follow-up	Primary Outcome Measures	Secondary Outcome Measures	Results
Ultrasound guidance, maximal tenderness	Not mentioned	4 wk	VAS score pain on walking	VAS pain at rest and during activity, ankle ROM, calf muscle circumference, tendon diameter, FIL, EQoL	No significant difference between groups
Maximal tenderness	Stretching, eccentric training prior to ESWT, sham	4, 8, 12 wk after completion	AOFAS score	VAS pain on walking, stairs, working, running	ESWT significantly more effective at 8 ($P = .01$) and 12 wk ($P = .04$)
Maximal tenderness, clinical focusing technique	Control: eccentric training per protocol with heel drop past neutral. Could take NSAIDs if necessary. All patients instructed to avoid painful activity, could lightly jog at 4 wk	12, 16 wk, 15 mo, after ESWT	VISA-A, general subjective outcome—patient, pain on NRS, pressure pain threshold, use of analgesics	Not specified	ESWT had significantly improved outcome measures over conservative group on subjective assessment, pain, pain threshold, tenderness, and VISA-A.
Maximal tenderness, clinical focusing technique	Treatment groups = ESWT with eccentric training per protocol. Could take NSAIDs if necessary. All patients instructed to avoid painful activity, could lightly jog at 4 wk. All cointerventions discouraged	4 mo	VISA-A, General subjective outcome —patient, pain on NRS	Not specified	At 4 mo, ESWT + eccentric loading had significantly better outcomes on VISA-A ($P = .0016$), general assessment ($P = .001$), pain ($P = .0045$)
Maximal tenderness, clinical focusing technique	Not specified	Average 14.5 and 15.3 mo with absence and presence of Haglund's deformity, respectively	VISA-A, 6-point Likert scale: success if patients rate themselves as 1 or 2, failure if 3-6	Not specified	At the follow-up time point, nondeformity group had significantly improved VISA-A compared to deformity group. No difference in patient-graded outcomes on Likert scale $P = .062$

and 9, with the first session consisting of 1000 shocks with an EFD of 0.10 mJ/mm^2, and the last session with 1500 shocks with an EFD of 0.30 mJ/mm^2. The duration till full recovery in the ESWT group was 59.7 days compared to 91.6 in the running program control group.

Additionally, there are notable case reports of success in treatment of MTSS in high-level athletes. Saxena

Table 6
Continued

Area Applied	Adjuvant Treatment	Follow-up	Primary Outcome Measures	Secondary Outcome Measures	Results
Not specified	Patients asked not to return to sports for minimum 3 wk. No other treatment	1 mo after completion, 6-12 mo, 13-24 mo, >24 mo	Average VAS pain, subjective clinical evaluation	Not mentioned	Significant improvement in pain ($P < .01$) at 1 mo, further improving towards 24 mo after treatment. Satisfactory results in 79.7% of patients at final evaluation
Maximal tenderness	No restriction on sports participations or concurrent treatment. Could take acetaminophen 3000 mg/qD for 2 d after treatment	1, 12, 22 wk after final treatment	VISA-P	VAS during ADLs and sports, after performing functional tests, maximal jumping test, triple-hop test, single-legged decline squat	No significant difference between groups in VISA-P or VAS, no treatment-time interaction effect. Only significant difference was subjective pain improvement 1 wk after final treatment in VAS

Table 7
Lower extremity studies characterizing effects of shockwave on management by condition: Hamstring tendinopathy

Author	Study Design	No. of Subjects	Subject Population	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions; Interval	Local Anesthesia
Cacchio 2011	RCT	40	Professional Athletes	11 mo	EMS Swiss Dolorclast	RSWT	2500 pulses, 10 Hz	0.18 mJ/mm^2, 4 bar	4; weekly	No

EFD = energy flux density; RCT = randomized controlled trial; RSWT = radial shockwave therapy; ROM = range of motion; NSAIDs = nonsteroidal anti-inflammatory drugs; PT = physical therapy; VAS = visual analog scale; NPRS = Nirschl Phase Rating Scale; ESWT = extracorporeal shockwave therapy.

et al [56] described treatment of 2 elite athletes diagnosed with MTSS, who were treated with ESWT and a graduated running protocol. The cases describe athletes who were able to continue participating in their sports safely, and in one case, one won an Olympic Gold Medal 17 weeks after treatment [56].

Nonunions, Avascular Necrosis, Stress Fractures

Shockwave therapy for the treatment of conditions such as nonunions, stress fractures, and avascular necrosis appears to be more widely accepted outside of the United States than within the United States [6]. Furia et al [6] report that many trauma centers in Europe and Asia regularly use ESWT to treat nonunions. Birnbaum et al [57] examined 10 studies and concluded that though ESWT yielded high healing rates, 75%-91%, this treatment was to remain considered "experimental" as there were no prospective RCTs. Efficacy appears to depend on the type of bone-related pathology, differentiating between nonunion, atrophy, or hypertrophy [58,59,60]. Cacchio et al [61] published a prospective RCT that compared ESWT in treatment of long-bone nonunions to surgical treatment. ESWT was found to be comparable to surgery in healing long-bone nonunions. ESWT may be an effective treatment for nonunion, but optimal dose and protocol must still be established.

Wang et al [62] studied ESWT versus core decompression and grafting in patients with avascular necrosis of the femoral head. Twenty-five months after treatment, patients treated with ESWT had improved pain and Harris Hip Scores. At long-term follow-up, 76% of the patients treated with ESWT showed good or fair clinical outcomes, compared with 21% of the surgical treatment group [63]. Taki et al [64] reported 5 cases in which ESWT was used to expedite healing in refractory stress fracture, in which radiographic improvement was seen within 1-1.5 months after treatment, and radiographic consolidation between 1-3.5 months after treatment.

Upper Extremity Pathology

Lateral Epicondylitis

Initial studies on the effect of ESWT for management of lateral epicondylitis found little benefit over placebo treatment [8,9,65-67]. Some issues with these

Table 8
Lower extremity studies characterizing effects of shockwave on management by condition: Greater trochanteric pain syndrome

Author	Study Design	No. of Subjects	Subject Population*	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions; Interval	Local Anesthesia
Furia 2009	Case Control	33	Mix of athletes/nonathletes: 52% ESWT recreational athletes, 45% control recreational athletes	6 mo	EMS Swiss Dolorclast	RSWT	2000 pulses, 10Hz	0.18 mJ/mm^2, 4 bar	1	No
Rompe 2009	RCT	229	Not specified	6 mo	EMS Swiss Dolorclast	RSWT	2000 pulses, 8Hz	0.12 mJ/mm^2, 3 bar	3; weekly	No

EFD = energy flux density; ESWT = extracorporeal shockwave therapy; RSWT = radial shockwave therapy; RCT = randomized controlled trial; VAS = visual analog scale; RM = Roles-Maudsley.
* The designation "not specified" was applied to studies that did not specify level of physical activity or sport of the population treated.

Table 7
Continued

Area Applied	Adjuvant Treatment	Follow-up	Primary Outcome Measures	Secondary Outcome Measures	Results
Maximal tenderness, clinical focusing technique	Unrestricted ROM and weightbearing after treatments, recommended ice after treatment for 4 hours after. Patients instructed to avoid activities/exercises that would increase severity of symptoms. Control: NSAIDs, PT, exercise program	1 wk, 3, 6, 12 mo after completion	Decrease of 3 points in mean pain VAS at the 3-mo follow-up, 2-phase decrease in NPRS	Degree of subjective recovery on 6-point Likert scale	Significant improvement in ESWT as compared to conservative group at 3 mo VAS ($P < .001$), NPRS ($P < .001$). Eighty percent in ESWT group returned to professional level of their sport vs 0% in traditional group

studies include use of local anesthesia [67], monthly frequency of treatments with a short follow-up of 3 months [9], low-dose ESWT as control treatment [65], and inadequate description in chronicity of symptoms [8].

In contrast, 2 studies have revealed a favorable response of ESWT for lateral epicondylitis. Pettrone and McCall [68] studied 114 patients with chronic lateral epicondylitis, as defined by symptoms for at least 6 months and failure of 2 conservative therapy treatments. The patients were randomized to receive ESWT for 3 weekly treatments (2000 impulses, EFD 0.06 mJ/mm^2) or sham treatment with a sound-reflecting pad between the head of the machine and the patient. At 12 weeks, patients in the placebo group could cross over into the active treatment group if they still met study criteria. At 12 weeks, there was a significant difference in pain reduction on the Thomsen test and on the VAS. There was a significant improvement in the upper extremity functional scores and patient activity scores in the treatment group at 12 weeks. Additionally, there was an improvement in grip strength in the treatment group, but this difference was not found to be significant ($P = .09$). At 1 year, 93% of the active treatment group reported at least 50% reduction in pain. Patients who chose to cross over to ESWT had observed improved pain scores compared to their prior pain scores during placebo treatment. The benefits in pain reduction were durable for nearly all who received ESWT over 12 months' follow-up [68]. Similarly Rompe et al [69] performed an RCT examining the effect of 3 weekly sessions of low-dose ESWT (0.09 mJ/mm^2) versus placebo for treatment of chronic lateral epicondylitis, with the primary outcome of improved pain during the Thomsen test at 3 months. Though reduced pain was noted in both groups 3 months after completion of treatment, the ESWT group was found to have statistically significant improvement compared with the control group (95% CI 0.6-2.4; $P = .001$). Twelve months post-treatment, the difference in pain reduction between groups persisted, but no longer remained significant.

In 2007, Rompe and Maffuli [70] conducted a systematic review of 10 studies that evaluated ESWT as treatment for lateral epicondylitis. Because of the clinical and methodologic heterogeneity, the results of the studies were not pooled for meta-analysis. The authors concluded that ESWT could be considered in restricted conditions only, and might yield improved outcomes in chronic recalcitrant cases.

Table 8
Continued

Area Applied	Adjuvant Treatment	Follow-up	Primary Outcome Measures	Secondary Outcome Measures	Results
Maximal tenderness, clinical focusing technique	Concomitant treatment discouraged. Stationary cycling permitted immediately, light running at 1 wk	1, 3, 12 mo after treatment	VAS score, Harris Hip Score (HHS), RM score. Two-point change on VAS, 10-point change on HHS considered clinically relevant	Not specified	ESWT yielded significantly improved outcomes at all time points compared to placebo
Maximal tenderness, clinical focusing technique	Could return to prior recreational activity after 6 wk	1, 4, 15 mo after treatment	Degree of recovery at 4 mo on 6-point Likert scale, severity of pain on VAS score	Degree of recovery and severity of pain at 1 mo, 15 mo; use of medication, medical visits, diagnostic tests, side effects, return to activity	ESWT significantly more effective than home training and steroid at 4 mo, ESWT equal to home training and better than corticosteroid injection at 15 mo

Table 9
Lower extremity studies characterizing effects of shockwave on management by condition: Medial tibial stress syndrome

Author	Study Design	No. of Subjects	Subject Population	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions	Local Anesthesia
Rompe 2010	Case-control	49	Athletes—running	6 mo, failed 3 nonsurgical treatments	EMS Swiss Dolorclast	RSWT	2000 pulses, 8Hz	0.10 mJ/mm^2, 2 bar	3; weekly	No
Moen 2012	Prospective control	42	Athletes	21 d	Duolith SD1	FSWT	1000-1500 pulses, 2.5 Hz	0.10-0.30 mJ/mm^2	5; 1, 2, 3, 5, 9 wk	Not specified

EFD = energy flux density; RCT = randomized controlled trial; FSWT = focused shockwave therapy; RSWT = radial shockwave therapy; NSAIDs = nonsteroidal anti-inflammatory drugs; NRS = numeric rating scale; ESWT = extracorporeal shockwave therapy.

Tendinopathy of the Shoulder

The first reported study on noncalcific rotator cuff tendinopathy was by Speed et al [10]. Investigators compared active ESWT delivered with an EFD of 0.12 mJ/mm^2 to sham treatment (0.04 mJ/mm^2, head deflated without coupling gel) for 3 treatments provided monthly. Both groups had improvements over 6 months, with investigators concluding that placebo benefits were seen in the use of ESWT for this condition [10]. Li et al [71] conducted a randomized, double-blind, placebo-controlled trial examining patients with chronic rotator cuff tendinitis without calcifications with symptoms for greater than 6 months. The intervention was 3000 pulses of radial shockwave and EFD of 0.11 mJ/mm^2. Five total treatments were provided with

Table 10
Lower extremity studies characterizing effects of shockwave on management by condition: Nonunion, Avascular Necrosis, Stress Fractures

Author	Study Design	No. of Subjects	Subject Population*	Minimum Duration of Symptoms	Shockwave Device	Type of Shock	Impulses/ Frequency	EFD	No. of Sessions; Interval	Local Anesthesia
Cacchio 2009	RCT	126	Not specified	6 mo	Group I: Dornier Epos Ultra, Group 2: Modulith SLK	FSWT	4000 pulses	Group 1: 0.40 mJ/mm^2, Group 2: 0.70 mJ/mm^2	4; weekly	Regional anesthesia—nerve block
Xu 2009	Retrospective cohort	69: 22 femur, 28 tibia, 13 humerus, 5 radius, 1 ulna	Not specified	6 mo	Ossatron	FSWT	3000-10 000 pulses based on location of fracture	0.56-0.62 mJ/mm^2 based on location	Unclear; unclear	Spinal or local anesthesia
Wang 2005	RCT	49	Not specified	Minimum not reported, average 5.9 and 7.1 ESWT and core decompression, respectively	Ossatron	FSWT	6000 total impulses, 1500 pulses in 4 points	0.62 mJ/mm^2	1	General anesthesia

EFD = energy flux density; RCT = randomized controlled trial; FSWT = focused shockwave therapy; RSWT = radial shockwave therapy; ESWT = extracorporeal shockwave therapy; NSAIDs = nonsteroidal anti-inflammatory drugs; DASH = Disabilities of the Arm, Shoulder, and Hand; LEFS = Lower Extremity Functional Scale; VAS = visual analog scale; PRN = pro re nata (on an as needed basis); ADL = activity of daily living; MRI = magnetic resonance imaging

* The designation "not specified" was applied to studies that did not specify level of physical activity or sport of the population treated.

Table 9
Continued

Area Applied	Adjuvant Treatment	Follow-up	Primary Outcome Measures	Secondary Outcome Measures	Results
Maximal tenderness, clinical focusing technique	Concomitant treatment discouraged until the 4-mo follow-up. NSAIDs allowed when requested. After 6 wk, could return to prior level of sport/activity. Stationary cycling permitted immediately, light running at 1 wk	1, 4, 15 mo from baseline	Degree at recovery at 4 mo on 6-point Likert scale	Degree at recovery at 1 and 15 mo, severity of pain during past week on NRS, current sports activities	ESWT with home training yielded significantly improved results in success rates and pain at all time points. 40/47 patients returned to their sport at 15 mo in ESWT group compared to 22/47 in control
Maximal tenderness	Graded running program: 6-phase	Unclear	Number of days from inclusion to completion of phase 6 (full recovery) of running program	If full recovery not reached, Likert scale used to assess recovery	Significantly faster recovery in ESWT + running program as compared to running program alone ($P = .008$)

each separated by 3 days. The outcomes were measured at 4 and 8 weeks after treatment, at which time all measures, pain by numeric rating scale, Constant-Murley Score (CMS), and Simple Shoulder Test, were significantly improved in the ESWT group over the control group [71]. Galasso et al [72] performed a double-blind, randomized, placebo-controlled study on 20 patients with noncalcifying supraspinatus tendinopathy and found significantly improved CMS and ROM in the ESWT group as compared to the placebo group.

Ioppolo et al [73] studied patients with calcific tendinitis of the supraspinatus tendon. Forty-six patients were randomized to either receive 4 weekly sessions of ESWT using 2400 pulses at 0.20 or 0.10 mJ/mm^2, and a control group was not present. The outcomes in terms of CMS and pain score on VAS were measured at 3

Table 10
Continued

Area Applied	Adjuvant Treatment	Follow-up	Primary Outcome Measures	Secondary Outcome Measures	Results
Center of fracture gap on ultrasound guidance and prior radiographs	Limb immobilized in cast/brace for 6 wk—3 mo. NSAIDs could be used once daily for 3 d after ESWT. Weightbearing could be resumed 3 d after ESWT.	3, 6, 12, 24 mo after treatment	Healing of nonunion by radiographic assessment at 6 mo	DASH/LEFS, VAS, Subjective efficacy	At 6 mo, ESWT groups had significantly improved clinical outcomes compared to surgical group ($P < .001$). Radiograph to demonstrate healing showed no difference between groups. At 12 and 24 mo, no difference between groups aside from ESWT, with significantly improved DASH over surgical group
C-arm	Avoidance of general activity for 1 wk, return to prior weight-bearing status 7 d after treatment	2, 3, 4, 6 mo and PRN after treatment	Radiographic callus formation/bony union	Not specified	ESWT was more successful in bony union for hypertrophic nonunions (90.9%) than for atrophic nonunions (0%). Total overall success 75.4% bony union
C-arm	Partial weight-bearing for 6 wk, acetaminophen for pain	1, 3, 6, 12 mo, yearly	VAS pain, Harris Hip Score (HHS), assessment of ADL and work capacity, radiographic assessment by radiography and MRI	Not specified	At 25 mo follow-up, ESWT group had significantly improved VAS and HHS ($P < .001$).

and 6 months after treatment. Interval change in radiographic appearance of calcific deposits was evaluated 6 months post-treatment. Both groups were found to have improved outcomes at each time point; however, the VAS scores were statistically reduced and the CMS were higher at 6 months in the higher energy group (0.20 mJ/mm^2). The authors also noted that clinical improvement did not correlate with a reduction in size of calcifications [73].

Bannuru et al [74] performed a systematic review examining 28 RCTs pooling 1745 patients with symptoms for 3-12 months. Patients with calcific and noncalcific tendinitis were included in this review. The authors found that high-energy ESWT (EFD $>$ 0.28 mJ/mm^2) was successful in improving pain, function, and resorption of calcifications in patients with calcific tendinitis. Low-energy ESWT was found to improve shoulder function in patients with calcific tendinitis; however, ESWT for treatment of noncalcific tendinitis at both high and low energy was not effective.

In 2017, Wu et al [75] examined 14 RCTs that evaluated several different treatment options for chronic calcific tendinitis of the shoulder, including high-energy FSWT, low-energy FSWT, radial shockwave, transcutaneous electrical nerve stimulation, and ultrasound-guided needling. They found that high-energy FSWT and radial shockwave were more effective than low-energy focused shockwave. Ultrasound-guided needling also appeared to produce beneficial results. Of all forms of ESWT, high-energy focused shockwave was found to be the best therapy for promoting functional recovery [75].

Adverse Effects of ESWT

In all studies, common side effects after ESWT include transient pain, skin erythema, pain, and local swelling. Two case reports were found that noted bone injuries [76,77]. The first described a patient who received ESWT for supraspinatus calcific tendinopathy, who showed improvement clinically and radiographically after treatment. Three years after treatment, she developed recurrent shoulder pain and was diagnosed with stage IV osteonecrosis of the humeral head. The authors of the case report mention that injury to the ascending branch of the anterior humeral circumflex artery may explain her presentation [76]. The second case involves a patient treated for plantar fasciitis with 2 sessions of ESWT within 10 days. After treatment, she noted worsening pain and greater difficulty ambulating. Her MRI revealed a linear calcaneal fracture that did not reach the opposite cortex. Three months later the fracture healed, and 12 months later her pain resolved [77]. A separate study identified 2 patients receiving focused shockwave who sustained Achilles tendon ruptures; both occurred within 2 weeks of treatment and were in older female patients ages 62 and 65 [46].

Conclusion

ESWT may result in beneficial effects for treatment of patients with various refractory musculoskeletal conditions including disease of tendons and plantar fascia. Notably, studies did have mixed results for most conditions, and studies with favorable outcomes did not report consistent improvement for all patients receiving ESWT. Individual response to ESWT likely varies based on a number of factors. The optimal protocol, including EFD, number of impulses, device, type of shockwave, number of treatment sessions, interval between sessions, and adjuvant treatment must still be determined for each condition. In patients who have failed to respond adequately to conservative treatment options and are presented with surgery as the next choice, ESWT may be a reasonable alternative treatment option that could produce results comparable or superior to those with surgical treatment [61].

Available literature would support use of low-energy radial shockwave treatment for most treatment applications mentioned in this review; focused high-energy shockwave appears to be more effective for calcific tendinopathy of the shoulder. The number of treatments varied between protocols; however, most studies demonstrating efficacy separated treatment by 1 week and provided a total of 3-5 treatment sessions. Not all protocols reported on the combined use of physical therapy. Philosophically, coupling ESWT to progressive physical therapy programs to restore tissue function may optimize response to treatment. Nerve block is not recommended during treatment according to available literature demonstrating poor outcomes when using anesthetics. Additionally, use of local analgesia may reduce the ability to use the clinical focusing technique to interactively identify sites of pathology and direct treatment. Additionally, NSAID use may be discouraged given the concern for disrupting normal inflammatory pathway that may be responsible for treatment response.

As physiatrists provide care to athletes and individuals with musculoskeletal and neurologic injuries, identifying effective treatments for pain is important to help facilitate function. Limitations in guiding use of ESWT include the small number of well-designed clinical trials to evaluate efficacy of treatment. Notably, few studies have evaluated athlete populations, and there are no recognized studies published to date in patients with underlying neurologic conditions or patients with non-musculoskeletal classes of disability. The studies evaluated in this review had low measured bias with exception of criteria of blinding the therapist administering placebo and treatment ESWT. Studies have created a variety of placebo ESWT conditions; however, the influence of not achieving complete blinding to comparative effectiveness cannot be determined. In addition to measures to optimize blinding of treatment,

studies are needed to compare ESWT to other interventions for treatment of tendon and ligament diseases, including platelet-rich plasma, tenotomy, and other treatments. Postprocedure guidelines do not currently exist to guide patients on appropriate graded return to exercise for most conditions following ESWT. Additionally, medical insurance and healthcare delivery in the United States does not routinely reimburse for ESWT treatment, creating a financial barrier. Despite these limitations, the current evidence does suggest ESWT may be a reasonable treatment to consider for management of chronic musculoskeletal conditions that fail to respond to conservative care given favorable safety profile and low risk for side effects.

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