Current Physical Medicine and Rehabilitation Reports (2019) 7:204–215
https://doi.org/10.1007/s40141-019-00229-4

SPORTS MEDICINE REHABILITATION (B LIEM AND BJ KRABAK, SECTION EDITORS)

Extracorporeal Shockwave Therapy in Lower Limb Sports Injuries

Haylee E. Borgstrom[1] · Amol Saxena[2] · Adam S. Tenforde[1]

Published online: 3 June 2019

Abstract

Purpose of Review To outline current evidence on the use of ESWT for the treatment of lower limb sports injuries.

Recent Findings There is growing evidence to support the use of extracorporeal shockwave therapy (ESWT) for a variety of musculoskeletal conditions in the general population. However, research focused on the use of ESWT specifically for lower extremity injuries in the athletic population is more limited. Athletes represent a subgroup of patients that may benefit from ESWT. Compared with injections or surgical interventions, athletes undergoing ESWT often are able to continue sports participation with fewer limitations in activity during treatment.

Summary The review identifies considerable variability in study design and treatment protocols that affect the overall quality of evidence. Sports participation was allowed in most studies. One case of plantar fascia tear was identified during ESWT treatment; this injury was self-limited. Most studies report pain-relieving and/or functional benefit with the use of ESWT for common lower extremity tendinopathies, plantar fasciitis, and medial tibial stress syndrome. This review highlights the need for further investigations on optimal methods of ESWT use in athletes given the high prevalence of lower extremity injuries and favorable safety profile for treatment.

Keywords Athlete · Sport · Extracorporeal shockwave therapy · ESWT · Lower extremity injury · Tendinopathy

Introduction

Extracorporeal shockwave therapy (ESWT) is a non-invasive treatment for a variety of injuries seen in athletes. While initially used for lithotripsy, over the past two decades, ESWT has been documented to improve pain and functional outcomes for musculoskeletal conditions including Achilles [1–7], patellar [8, 9•, 10–12], proximal hamstring [13], and gluteal tendinopathies [14–16], as well as plantar fasciitis [17–24], medial tibial stress syndrome (MTSS) [25–27], and bony non-unions or stress fractures [28–32]. Prior reviews and systematic methods to quantify efficacy often include study populations with a mix of both athletes and non-athletes [33–35] and report the best evidence for use in the treatment of plantar fasciitis [36]. To our knowledge, a review of current evidence on ESWT in the treatment of lower limb injuries in the athletic population has not been performed. Athletes represent an important subgroup of patients with unique treatment considerations compared with the general population. They may further benefit from ESWT for recalcitrant lower limb injuries given its less invasive nature compared with regenerative injections or surgical interventions, lack of post-treatment immobility or activity limitation, and potential for quicker return to sport with improved performance and reduced pain. Thus, the aim of this narrative review is to provide an overview of current research evaluating the effect of ESWT for the treatment of lower limb sports injuries.

This article is part of the Topical Collection on *Sports Medicine Rehabilitation*

✉ Adam S. Tenforde
atenforde@mgh.harvard.edu

1 Spaulding Rehabilitation Hospital, Department of Physical Medicine and Rehabilitation, Harvard Medical School, 300 1st Avenue, Charlestown, MA 02129, USA

2 Department of Sports Medicine, Palo Alto Medical Foundation, Palo Alto, CA, USA

Proposed Mechanisms of Action

To date, there are numerous proposed mechanisms of action related to both the direct effects of shockwaves on damaged tissues and the indirect effects on local metabolic and inflammatory milieu. Potential direct effects include disruption of chronic calcifications [37] and nociceptor hyperstimulation resulting in altered local neuropeptide release and neurotransmission of pain signals [38]. Potential indirect effects include entheses neovascularization [39], elevated concentrations of local growth factors and inflammatory cytokines [40], and tenocyte proliferation and stimulation of collagen synthesis [41], among others—all contributing to re-initiation of the healing cascade of injury. A summary of this key literature is outlined in recent review articles [34, 36] and is otherwise beyond the scope of this article.

Two primary forms of ESWT are focused (F-SWT) and radial (R-SWT) shockwave therapies. Focused shockwaves have higher energy, deeper tissue penetrance, and are applied by piezoelectric, electromagnetic, and electrohydraulic systems, whereas radial shockwaves have lower energy, superficial effect, and are ballistic in nature [42]. With many proposed mechanisms of action, ESWT likely has multiple effects contributing to tissue healing and pain relief.

Methodology

In March 2019, a literature review was conducted utilizing PubMed database and Google Scholar search engine to identify primary literature related to the use of ESWT in lower limb sports injuries. The search terms included extracorporeal shockwave therapy, ESWT, shock wave, athlete, sport, tendinopathy, tendonitis, fasciopathy, fasciitis, medial tibial stress syndrome, and stress fracture. Additional articles were identified by cross-referencing the resulting articles. Given limited published studies evaluating ESWT solely in athletic populations, the literature search was expanded to include studies with retrospective designs and subject populations that included at least 50% athletes. Case reports were not included. All articles were published in English. References were evaluated by two authors independently. This literature search resulted in a total of 22 original articles, including 10 randomized controlled trials (RCTs), 6 prospective cohort studies, 4 retrospective case-control studies, and 2 case series (Table 1). These articles are presented by diagnosis, highlighting the important aspects of study design, presence or absence of control group, athlete demographics, ESWT protocol specifics, and summary of outcomes. A detailed description of each original article included in this literature review can be referenced in Table 2.

Table 1 Total number of articles included in literature review based on diagnosis

Diagnosis	Number of articles
Medial tibial stress syndrome	4 (2 RCT, 1 PC, 1RCC)
Patellar tendinopathy	5 (3 RCT, 2 PC)
Plantar fasciitis	4 (2 RCT, 2 PC)
Achilles tendinopathy	4 (1 RCT, 1 PC, 2 RCC)
Proximal hamstring tendinopathy	1 (RCT)
Greater trochanteric pain syndrome	1 (RCC)
Stress fracture	2 (2 RCS)
Osteitis pubis	1 (RCT)

RCT, randomized controlled trial; *PC*, prospective cohort; *RCC*, retrospective case-control; *RCS*, retrospective case series

Results

Medial Tibial Stress Syndrome

A total of four primary articles were identified on the use of ESWT to treat MTSS in athletes, two randomized controlled trials (RCTs), one prospective cohort study, and one retrospective case-control study. In 2017, Gomez et al. and Newman et al. both performed RCTs on populations of military cadets and active adult runners, respectively [43•, 44•]. Gomez et al. reported that a single session of F-SWT plus a stretching and strengthening exercise program was superior to an exercise program alone after 1 month, resulting in increased treadmill running duration, decreased pain, and better treatment success scores [43•]. In contrast, Newman et al. compared F-SWT with sham ESWT for 5 sessions over 9 weeks and found that both groups improved with no added benefit of F-SWT related to clinically significant pain on palpation, pain or functional limitation during running, or global rating of change at the 10-week endpoint [44•].

Differences in study design between the two RCTs may have influenced outcomes. Gomez et al. studied a single session of F-SWT with a total cumulative dose of 300 mJ/mm2, while Newman et al. studied a total of 5 sessions of F-SWT with a total cumulative dose of 1450 mJ/mm2. There was further variability in number of pulses, energy flux density (EFD), and frequency during each session. Additionally, the control groups in these two studies received different interventions—standard exercise program or sham ESWT with lowest EFD setting. Authors in the Newman study postulated that sham ESWT protocol consisting of a total cumulative dose of 70 mJ/mm2 may have therapeutic benefit in treating MTSS, contributing to non-significance compared with the treatment group. Without a true control group, it is difficult to determine the effect of sham intervention over natural history resulting in improvement over time. Furthermore, these studies included two different populations of athletes, active military cadets and recreational runners. Notably, both studies did not have measured outcomes to 12 weeks when full anticipated effects of ESWT are often observed.

Two additional reports on benefits of ESWT for MTSS were observed from earlier non-randomized studies. A prospective cohort study conducted by Moen et al. in 2012 [26]

Table 2 Detailed summary of key literature related to the use of ESWT in lower limb sports injuries

Diagnosis	Author	Year	Study Design	Participants	Treatment	Summary
Medial tibial stress syndrome	Gomez et al.	2017	RCT	42 military cadets (33M, 9F), unilateral symptoms × 3+ weeks	F-SWT (Duolith SD1, EM) × 1 session (1500 pulses, EFD 0.2 mJ/mm2, 5 Hz) + exercise ($n = 23$) vs exercise alone ($n = 19$)	At 4 weeks, ESWT + exercise group had increased treadmill running test duration compared with exercise only group (17.5 vs 4.5 min), as well as decreased VAS after running and better treatment success scores.
	Newman et al.	2017	RCT	28 active adults (10M, 18F), symptoms × 3+ weeks	F-SWT (Duolith SD1, EM) × 5 sessions over 9 weeks (1500 pulses, EFD progressed from 0.1 to 0.3 mJ/mm2; $n = 14$) vs sham SWT (1500 pulses, EFD 0.01 mJ/mm2; $n = 14$)	At 10 weeks, pain on palpation was decreased by one point more in the F-SWT group compared with sham SWT. No differences in pain during running, pain-limited distance, or global rating of change scores between groups.
	Moen et al.	2012	Prospective cohort	42 athletes (23M, 19F), symptoms × 3+ weeks; running (19%), soccer (13%), field hockey, tennis, basketball, dancing	F-SWT (Duolith SD1, EM) × 5 sessions over 9 weeks (1000–1500 pulses, EFD 0.1–0.3 mJ/mm2, 2.5 Hz) graded running program ($n = 22$) vs graded running program alone ($n = 20$)	Time to full recovery (defined as being able to run 18 min consecutively without pain) was reduced in the ESWT + running program group compared with running program only group (60 vs 91 days).
	Rompe et al.	2010	Retrospective case control	94 running athletes (40M, 54W), unilateral symptoms × 6+ months	R-SWT (Swiss DolorClast) × 3 sessions over 3 weeks (2000 pulses, EFD 0.1 mJ/mm2, 8 Hz) + home exercise program vs home exercise program only	At 1, 4, and 15 months, R-SWT + home exercise group had better treatment success compared with home exercise alone group, as measured on a 6-point Likert scale (30% vs 13%, 64% vs 30%, 76% vs 37%), as well as reduced pain levels at all time points. At 15 months, 40/47 athletes in the treatment group had returned to sport compared with 22/47 in the control group.
Patellar tendinopathy	Thijs et al.	2017	RCT	52 active adults involved in sports at least once weekly (38M, 14F), symptoms × 2+ months; soccer (23%), running (21%), cycling (15%), and others	F-SWT (Swiss PiezoClast, PE) × 3 sessions over 3 weeks (1000 pulses, EFD 0.2 mJ/mm2, 4 Hz) + eccentric exercise ($n = 22$) vs sham ESWT (1000 pulses, 0.03 mJ/mm2, 4 Hz) + eccentric exercise ($n = 30$)	At 24 weeks, there were no differences in measures of severity/functional limitations/ability to participate in sport (VISA-P), VAS pain during squatting/jumping, and treatment success scores between groups.
	Vetrano et al.	2013	RCT	46 elite and non-elite athletes (37M, 9F), unilateral symptoms × 6+ months, US-confirmed proximal patellar tendinopathy; basketball (50%), volleyball (44%), soccer (6%)	F-SWT (Modulith, EM) × 3 sessions over (focused, 2400 pulses, EFD 0.17–0.25 mJ/mm2; $n = 23$) vs PRP injection × 2 over 2 weeks ($n = 23$)	At 2, 6, and 12 months, both groups had improved measures of severity/functional limitations/ability to participate in sport (VISA-P, modified Blazina) and VAS pain compared with baseline. These improvements were more pronounced in the PRP group compared with the F-SWT group at 6 and 12 months. At 12 months, PRP group had better treatment success scores (91% vs 61%).
	Zwerver et al.	2011	RCT	62 athletes in first half of season (41M, 21F), unilateral or bilateral symptoms × 3–12 months; volleyball (92%), basketball (6%), handball (2%)	F-SWT (Pizowave, PE) × 3 sessions over 3 weeks (2000 pulses, EFD 0.1–0.58 mJ/mm2 based on tolerability [mean 0.25], 4 Hz; $n = 31$) vs sham SWT (same protocol but without transmission gel, EFD less than 0.03 mJ/mm2; $n = 31$).	At 1, 12, and 22 weeks, there were no differences in measures of severity/functional limitations/ability to participate in sport (VISA-P) or VAS pain between groups. At 1 week, treatment satisfaction was greater in F-SWT group compared with sham SWT (65% vs 32%), but this effect was not sustained. No difference

Table 2 (continued)

Diagnosis	Author	Year	Study Design	Participants	Treatment	Summary
						in sport participation or training hours between groups.
	Vulpiani et al.	2007	Prospective cohort	73 athletes (54M, 19F), unilateral or bilateral symptoms × 3+ months, confirmed on US and imaging (67% inferior patellar pole, 11% tibial tuberosity, 22% intratendinous); 54% volleyball and basketball, 18% professional, 56% amateur, 26% occasional (at least weekly) participation	F-SWT (unspecified Storz device, EM) × 3–5 sessions (average 4, range 3–5) at 2–7 day intervals (focused, 1500–2500 pulses, EFD 0.08–0.44 mJ/mm2 based on tolerability [mean not reported])	At 1 month, VAS pain and measures of severity/functional limitations/ability to participate in sport (modified Blazina) were improved compared with pre-treatment, with sustained to further improved effect up to 24 months post-treatment. Treatment satisfaction improved from 43% at 1 month to 79.8% at greater 2 years post-treatment.
	Peers et al.	2003	Prospective cohort	27 athletes (21M, 6F), symptoms × 6+ months, confirmed on US; Jogging, track & field, volleyball, soccer	F-SWT (Sonocur plus, EM) × 3 sessions (1000 pulses, EFD 0.08 mJ/mm2, 4 Hz; $n = 15$) vs surgical treatment ($n = 14$)	At ~2 years, there was no difference in measures of severity/functional limitations/ability to participate in sport (VISA) and VAS pain in ESWT group compared with surgical group. Satisfaction with treatment scores were similar between groups. The ESWT group did not experience work incapacity, while the surgical group was able to return to work in an average of 6 weeks.
Plantar fasciitis	Saxena et al.	2017	Prospective cohort	28 participants (16M, 12F; 71% recreational athletes), symptoms for <3 months in early group vs > 6 months in standard/control group; Running (43%), tennis (14%), dancing, golfing, hiking	R-SWT (EnPuls) × 3 sessions over 3 weeks (2500 pulses, EFD 0.16 mJ/mm2, 10 Hz) both early group (n = 14) and standard/control group (n = 14)	At 3 and 12 months, both groups had similarly improved VAS pain and treatment success scores compared with baseline. At 12 months, all of the early group had returned to desired activity level compared with 9/14 in the standard group.
	Saxena et al.	2012	RCT (F-SWT vs sham ESWT) + prospective cohort arm (surgery)	37 athletes (21 M, 16F), symptoms × 6+ months; runners with 25+ weekly mileage or other athletes practicing sport 6+ hours weekly	F-SWT (Duolith, EM) × 3 sessions over ~3 weeks (2000 pulses, EFD 0.24 mJ/mm2, 4 Hz); $n = 11$) vs sham SWT (same protocol but with shockwave-blocking head; n = 14) vs surgical treatment ($n = 12$)	At 12 months, there were no differences in improvement in VAS pain or treatment success scores between F-SWT vs sham SWT groups. The surgical group had lower VAS pain and better treatment success scores compared with both F-SWT and sham SWT groups. However, pre-treatment VAS pain score was significantly lower in surgical group than F-SWT group. Return to activity ranged from immediate to 2 months for F-SWT (with 2 eventually undergoing surgery), immediate to 6 months for sham SWT (with 2 unable to return to sport), and 2–4 months (mean 2.8) for surgical group.
	Moretti et al.	2006	Prospective cohort	54 running athletes (M:F not reported), unilateral symptoms × 6+ months + heel spur confirmed on XR; 37% competitive, 63% recreational	F-SWT (Minilith, EM) × 4 sessions over 4 weeks (2000 pulses, EFD 0.04 mJ/mm2)	At 1.5, 6, and 24 months, VAS was significantly reduced compared baseline. 50/54 athletes returned to sport after an average of 34 days post-treatment. Heel spur remained stable on follow-up XR. There was a correlation (r = 0.30) between reduced VAS and resolution of inflammation on ultrasound examination at 24 months.
	Rompe et al.	2003	RCT	45 long-distance running athletes (22M, 23F), symptoms × 12+ months	F-SWT (Sonocur Plus, EM) × 3 sessions over 3 weeks (2100 pulses, EFD 0.16 mJ/mm2,	At 6 and 12 months, F-SWT group had reduced VAS pain on morning walking compared with sham group (2.1 vs 4.7, 1.5 vs 4.4)

Table 2 (continued)

Diagnosis	Author	Year	Study Design	Participants	Treatment	Summary
					4 Hz; $n = 22$) vs sham SWT (same protocol but with sound-absorbing pad; $n = 23$)	and better treatment success scores. After 6 months, 60% of F-SWT group reported greater than 50% improvement compared with 27% in sham SWT.
Achilles tendinopathy	Vulpiani et al.	2009	Prospective cohort	105 athletes (89M, 16F), symptoms >6 months, 22 with bilateral symptoms, confirmed on imaging with 66% insertional and 34% non-insertional; 10% professional, 60% amateur, 30% occasional (at least weekly) participation	F-SWT (unspecified Storz device, EM) × 3–5 sessions (mean 4) at 2–7 day intervals (1500–2500 pulses, EFD 0.08–0.33 mJ/mm2 for mid-portion and 0.12–0.40 mJ/mm2 for insertional tendinopathy based on tolerability [mean not reported]), 11 underwent second cycle, all instructed not to return to sport for 3 weeks post-treatment	At 2 months and 6–12 months, VAS pain and measure of severity/functional limitations/ability to participate in sport decreased compared with baseline. This improvement persisted at 12–24 months. Treatment satisfaction scores were better in those with mid-portion compared with insertional tendinopathy at all time points (75% vs 37% at 12–24 months).
	Rompe et al.	2008	RCT	50 participants with insertional tendinopathy (58% athletes; 20M, 30F), symptoms × 6+ months	R-SWT (Swiss Dolorclast) × 3 session over 3 weeks (2000 pulses, EFD 0.12 mJ/mm2, 8 Hz; $n = 25$) vs eccentric loading (n = 25)	At 4 months, R-SWT group had greater improvements in measures of severity/functional limitations/ability to participate in sport (VISA-A), VAS pain, algometer pain threshold, and treatment success scores compared with eccentric loading group. The benefits of F-SWT are reported to be stable at 1 year. Allowing crossover from eccentric loading to R-SWT at 4 months, 13 of 18 reported treatment success.
	Furia	2008	Retrospective case control	68 participants with non-insertional tendinopathy (50% recreational athletes; 22M, 46F), symptoms > 6 months	F-SWT (Dornier Epos Lithotripser, EM) × 1 session (3000 pulses, EFD 0.21 mJ/mm2, 6 Hz, regional anesthesia; $n = 34$) vs conservative care (n = 34)	At 1, 3, and 12 months, F-SWT group had lower VAS pain and higher treatment success scores compared with control. There was no significant difference in total number of athletes able to return to sport between F-SWT and control groups (14/18 vs 10/16).
	Furia	2006	Retrospective case control	68 participants with insertional tendinopathy (62% recreational athletes; 24M, 44F), symptoms > 6 months	F-SWT (Dornier Epos Lithotripser, EM) × 1 session (3000 pulses, EFD 0.21 mJ/mm2, 6 Hz, 12 with local and 23 with nonlocal anesthesia; $n = 35$) vs conservative care ($n = 33$)	At 1, 3, and 12 months, F-SWT group had lower VAS pain and higher treatment success scores compared with control. The F-SWT subgroup with local anesthesia had less improvement in VAS pain score compared with nonlocal anesthesia subgroup. There was no significant difference in total number of athletes able to return to sport between F-SWT and control groups (20/22 vs 14/20).
Proximal hamstring tendinopathy	Cacchio et al.	2011	RCT	40 professional athletes (27M, 13F) with MRI-confirmed chronic PHT; running, jumping, hurdling, soccer, rugby	R-SWT (Swiss DolorClast) × 4 sessions over 4 weeks (2500 pulses, EFD 0.18 mJ/mm2, 10 Hz; $n = 20$) vs traditional conservative care ($n = 20$)	At 1 week, 3, 6, and 12 months, R-SWT group had reduced VAS pain and improved functional limitation scores compared with traditional care group. At 3 months, 85% of R-SWT group reported at least 50% reduction in pain compared with 10% in traditional care group. Also at 3 months, 80% of the R-SWT group compared with 0% of the traditional care group had returned to sport.
Greater trochanteric pain syndrome	Furia et al.	2009	Retrospective case control	66 participants (49% recreational athletes; 22M, 44F), symptoms ≥6 months,		At 1, 3, and 12 months, ESWT group had improved VAS pain and Harris hip scores

Table 2 (continued)

Diagnosis	Author	Year	Study Design	Participants	Treatment	Summary
				confirmed transient improvement with local anesthetic injection	R-SWT (Swiss DolorClast) × 1 session (2000 pulses, EFD 0.18 mJ/mm2, 10 Hz; $n = 33$) vs conservative care ($n = 33$)	compared with control group. At 12 months, treatment satisfaction scores were better in the ESWT group compared with control group. In the ESWT group, 13/17 athletes returned to sport compared with 10/15 in control group.
Stress fracture	Moretti et al.	2009	Retrospective case series	10 male elite and sub-elite soccer players with delayed union or non-union of stress fractures (si× 5th metatarsal (MT), four tibia), confirmed on imaging	F-SWT (Minilith, EM) × 3 sessions for MT and 4 sessions for tibia stress fractures every 48 h (4000 pulses, EFD 0.09–0.17 mJ/mm2). After F-SWT, patients with MT fractures wore cast × 6 weeks. All athletes instructed to rest for 6–8 weeks.	At 6–14 weeks, repeat radiographs revealed bony fusion in all athletes. All athletes returned to sport 3–10 months post-treatment without pain or functional limitation.
	Taki et al.	2007	Retrospective case series	5 athletes (4M, 1F) with delayed union or non-union of stress fractures × 6–12 months (2 tibial, 5th MT, inferior pubic ramus, medial malleolus); baseball (2), basketball (1), soccer (1), marathon (1)	F-SWT (OssaTron, EH) × 1 session under anesthesia (2000–4000 pulses, 0.29–0.4 mJ/mm2). After ESWT, cast × 4 weeks for 2 cases with pseudoarthroses and rest for others.	After an average of 2.9 months, radiographic bony fusion developed in all cases. The average time to return to sport was 4 months.
Osteitis pubis	Schöberl et al.	2017	RCT (ESWT + rehab vs sham ESWT + rehab) + prospective cohort arm (sport limitation)	95 amateur male soccer players, duration of symptoms not described, diagnosis confirmed on MRI	F-SWT (Duolith, EM) × 3 sessions over 3 weeks (1500 pulses, EFD not reported, 15–21 Hz) + intensive rehab program ($n = 26$) vs sham SWT (1500 pulses, device that reabsorbs shockwaves) + intensive rehab program ($n = 18$) vs sport activity limitation ($n = 51$)	At 1 and 3 months, F-SWT + rehab group had reduced VAS pain and improved severity/functional limitations/ability to participate in sport/quality of life (HOOS) measures compared with sham SWT + rehab group. F-SWT + rehab group returned to sport earlier than sham SWT + rehab group (73 vs 103 days). Within 4 months, 42/44 players in RCT arm had returned to sport with no recurrence at 1 year. At 8 months, all athletes in the sport limitation group had returned to sport with 51% experiencing recurrent groin pain.

ESWT, extracorporeal shockwave therapy; *F-SWT*, focused shockwave therapy; *R-SWT*, radial shockwave therapy; *EM*, electromagnetic; *EH*, electrohydraulic; *PE*, piezoelectric system; *EFD*, energy flux density and a retrospective case-control study by Rompe et al. in 2010 [27] found benefit of ESWT in treating MTSS in athletes. Moen et al. reported decreased time to full recovery after 5 sessions of F-SWT over 9 weeks with a graded running program compared with a graded running program alone (average recovery was 60 vs 91 days, respectively) [26]. This study was primarily evaluating runners and soccer players, with other athletes from field hockey, basketball, tennis, and dance. In a retrospective study including 94 runners, Rompe et al. reported that 3 weekly sessions of R-SWT plus a twice-daily home exercise program performed over 12 weeks resulted in reduced pain and improved treatment success scores at 1, 4, and 15 months post-treatment compared with home exercise program alone [27]. Furthermore, return to primary sport at preinjury level was achieved in 85% of the intervention group compared with 47% of the control group at 15 months [27]. The advantages to both of these studies are the longer durations of follow-up for outcomes, which may partially explain positive results. A distinct weakness is lack of randomization. Given that ESWT is often not covered by insurance, non-RCT study designs may introduce bias for positive results as participants included in treatment groups may have opted to pay out-of-pocket for therapy.

Patellar Tendinopathy

A total of five primary articles were identified on the use of ESWT to treat patellar tendinopathy in athletes, three RCTs and two prospective cohort studies. Of the three RCTs, two included control groups exposed to sham ESWT and one to platelet-rich plasma (PRP) injections. In 2017, Thijs et al. performed an RCT and found no added benefit of combined F-SWT and eccentric exercises compared with sham ESWT with lowest EFD setting and eccentric exercises on VISA-P, VAS pain during squatting and jumping exercise, or treatment success scores at 6, 12 or 24 weeks [9•]. Total cumulative doses were 600 and 90 mJ/mm2 in the treatment group and sham groups, respectively. Again, this brings into question the possibility of a therapeutic effect from the sham ESWT. Participants included in this study were adults active in sport at least once weekly with symptoms for two or more months.

In 2013, Vetrano et al. conducted an RCT comparing 3 sessions of weekly F-SWT to two weekly ultrasound-guided platelet-rich plasma (PRP) injections for treatment of patellar tendinopathy in elite and non-elite basketball, volleyball, and soccer athletes [10]. Both groups had similarly improved VISA-P, VAS pain, and modified Blazina scores at 2 months compared with baseline, and PRP had superior outcomes to F-SWT at 6 and 12 months. At conclusion, treatment success was reported in 91% of athletes in the PRP group compared with 61% in the ESWT group [10]. Both study arms completed the same post-intervention stretching and strengthening program for 2 weeks, followed by aquatic exercise, then gradual return to sport at 4 weeks. While these protocols are typical and appropriate after PRP administration, a potential benefit of ESWT is allowing the athlete to continue training and sport participation post-treatment; thus, potential early functional benefits of ESWT compared with PRP injection may have been overlooked with this study protocol.

In 2011, an RCT by Zwerver et al. found that in-season volleyball (92%), basketball, and handball players were able to continue sport participation with no difference in training hours after receiving 3 sessions of F-SWT vs sham ESWT with lowest EFD setting [45]. Additionally, there were no differences in improvement in VISA-P or VAS pain scores. While treatment satisfaction was higher for ESWT after 1 week, this effect was not sustained. Total cumulative doses were 1500 and less than 180 mJ/mm2 in the treatment group and sham groups, respectively.

Two earlier prospective cohort studies were conducted by Vulpiani et al. in 2007 [11] and Peers et al. in 2003 [12]. In an uncontrolled study, Vulpiani et al. found that F-SWT for patellar tendinopathy in primarily jumping athletes of professional (18%), amateur (56%), and occasional recreational status resulted in improved VAS pain and modified Blazina scores at one month post-treatment with further improvements out to 24 months post-treatment [11]. Treatment satisfaction approached 80% at the conclusion of the study (greater than 2 years follow-up). Peers et al. compared F-SWT to surgical treatment and found no difference in VISA or VAS pain scores at 2 years [12]. Of note, the surgical group was not able to return to work for an average of 6 weeks, while the ESWT group had no work limitations during or following treatment.

Plantar Fasciitis

A total of four primary articles were identified on the use of ESWT to treat plantar fasciitis in athletes, two RCTs and two prospective cohort studies. In 2017, Saxena et al. conducted a prospective cohort study investigating the effect of three sessions of weekly R-SWT in 28 participants with plantar fasciitis, 71% being recreational athletes [18•]. Total cumulative dose was 1200 mJ/mm2 for all participants. Participants with symptoms for less than 3 months were included in the early intervention group, while participants with symptoms for 6 or more months were included in the standard or control group. During treatment, one patient sustained a plantar fascia rupture running up the stairs and was able to return to running at 6 weeks following this injury. At 3 and 12 months' post-treatment, there was no significant between-group difference for VAS pain scores. However, while treatment success scores were not significantly different between groups, all of the participants in the early intervention group had returned to desired level of activity at 1 year compared with 64% of the standard intervention group [18•]. Authors concluded that earlier implementation of R-SWT for treatment of plantar fasciitis is beneficial in athletes to allow for maintained activity level. Without a true control group, the magnitude of differences in gains during R-SWT for the early plantar fasciitis group is difficult to discern compared with natural history of the condition being self-limited in some athletes.

In 2012, Saxena et al. performed an RCT of three sessions of weekly F-SWT compared with sham ESWT with shockwave-blocking head. No additional benefits on VAS pain or treatment scores were observed in the treatment arm compared with the sham arm [21]. Total cumulative dose was 1440 mJ/mm2 for the ESWT group and was not reported for the placebo group. When compared with a prospective cohort of athletes undergoing endoscopic plantar fasciotomy, surgical intervention was found to have greater pain relief and treatment success scores compared with F-SWT, but longer return to sport [21]. This finding suggests an important potential benefit of ESWT compared with surgery, particularly for athletes in season.

Rompe et al. reported in 2003 using RCT design that long-distance runners undergoing three sessions of weekly F-SWT using low-energy setting (total cumulative dose 1008 mJ/mm2) had reduced VAS pain on morning walking and better treatment success scores compared with sham ESWT (total cumulative dose not reported) [24]. A prospective cohort study by Moretti et al. in 2006 enrolled patients with plantar fasciitis and associated painful heel spurs identified by radiograph. Investigators reported significant pain relief at each time point up to 2 years after four sessions of weekly F-SWT on low-energy settings (total cumulative dose 320 mJ/mm2) compared with baseline in running athletes [23]. In total, 93% of athletes were able to return to sport after an average of 34 days (range 24–45 days). Radiographs revealed stable heel spurs in all athletes post-treatment. Repeat ultrasound examination at 2 years revealed resolution of edema and/or bursal fluid at the proximal insertion of the plantar fascia in 61% of athletes, correlating with the degree of VAS pain reduction ($r = 0.30$) [23].

Achilles Tendinopathy

A total of four primary articles were identified on the use of ESWT to treat Achilles tendinopathy in athletes, one RCT, one prospective cohort study, and two retrospective case-control studies. Vulpiani et al. conducted a prospective cohort study investigating the effect of F-SWT in 105 athletes with insertional or non-insertional Achilles tendinopathy as confirmed on imaging [3]. Athletes underwent three to five sessions of F-SWT at 2–7-day intervals. Up to 24 months post-treatment, VAS pain and measures of functional and sport limitations were improved compared with baseline. Treatment satisfaction scores were better in those with non-insertional compared with insertional tendinopathy at all time points, up to twice as high at 12–24 months [3]. Of note, EFD varied based on the location of tendinopathy. Those with insertional tendinopathy received higher EFD compared with those with non-insertional tendinopathy, but with widely overlapping ranges and no reported mean EFD. This makes interpretation of findings based on the location of Achilles tendinopathy challenging given potential for dose-dependent response. Furthermore, 11 participants who did not respond adequately completed a second cycle of ESWT. It was not reported whether these were athletes with insertional or non-insertional tendinopathy, which could also affect total cumulative dose between subgroups. All athletes were instructed not to return to sport for 3 weeks after ESWT. The results at 12–24 months were reported as satisfactory in 75% of non-insertional and 37.4% of insertional tendinopathy cases ($P < 0.01$ for differences between location).

In the remaining three studies, it is important to note that subject populations were comprised of only 50–60% recreational athletes with the remainder being non-athletes. These studies were included given the relative paucity of literature related to ESWT and Achilles tendinopathy in athletes. In a 2008 RCT by Rompe et al., participants with insertional Achilles tendinopathy underwent either three sessions of weekly R-SWT (total cumulative dose 720 mJ/mm2) or eccentric loading exercises [6]. At 4 months, the R-SWT group was found to have improved VAS pain, functional and sport limitation (VISA-A), algometer pain threshold, and treatment success scores compared with control [6]. These benefits were reported to be stable at 1 year in the original allocation. Crossover design was allowed at 4 months. Of the 18 participants who received shockwave after failure to improve with eccentric loading program only, 13 achieved success. In contrast, 9 participants who failed to improve with R-SWT had surgery ($n = 1$, successful outcome) or received eccentric loading with only 2 of 8 reporting success.

In two retrospective case-control studies by Furia in 2006 [7] and 2008 [4], a single session of F-SWT (total cumulative dose 630 mJ/mm2) resulted in improved pain relief and treatment success scores compared with standard conservative care up to 12 months post-treatment for participants with insertional and non-insertional Achilles tendinopathy, respectively. There was no significant difference in number of athletes able to return to sport between the ESWT groups and control groups in these two studies, though there does appear to be a trend toward increased return to sport in the EWST groups. It is likely that low sample sizes impede detection of potential statistical differences. In the 2006 study by Furia, a subgroup analysis of those undergoing F-SWT found better results in those who did not receive local anesthesia [7]. Though still somewhat controversial [35], this finding bears specific mentioning as it has been demonstrated in other populations [46] and has contributed to a shift in clinical practice away from utilizing local anesthesia during ESWT.

Proximal Hamstring Tendinopathy

One RCT was identified on the use of ESWT to treat PHT in athletes. In 2011, Cacchio et al. studied the effect of 4 sessions of R-SWT (total cumulative dose of 1800 mJ/mm) compared with conservative care in 40 professional athletes [13]. Sports included running, jumping, hurdling, soccer, and rugby. At each time point following last treatment (3, 6, and 12 months), the R-SWT group had reduced VAS pain and improved functional limitation scores compared with control. At 3 months, 85% of the R-SWT group reported at least 50% pain reduction and 80% had returned to sport. In comparison, only 10% of the control group achieved at least 50% pain reduction and none had returned to sport.

Greater Trochanteric Pain Syndrome

One retrospective case-control study by Furia et al. in 2009 was identified on the use of R-SWT to treat greater trochanteric pain syndrome [15]. A total of 66 participants with symptoms for 6 months or longer were included, with half being recreational runners. Diagnosis was confirmed by transient symptom improvement after peritrochanteric local anesthetic injection. Participants underwent either one session of R-SWT (total cumulative dose of 360 mJ/mm2) or conservative care. At 1, 3, and 12 months, the R-SWT group had reduced VAS pain, improved Harris hip scores, and higher treatment satisfaction compared with control group. A total of 13/17 athletes in the R-SWT group and 10/15 athletes in the control group were able to return to sport.

Stress Fracture

A total of two primary articles, both retrospective case series, were identified on the use of ESWT to treat stress fractures in athletes. In 2009, Moretti et al. reported on 10 cases of male elite and sub-elite soccer players with delayed union or non-union of stress fractures localized to 5th metatarsal ($n = 6$) or anterior tibia cortex ($n = 4$) that were visualized on plain radiographs [30]. Athletes underwent 3 sessions (metatarsal) or 4 sessions (tibia) of F-SWT every 48 h. One patient with metatarsal stress fracture required repeat treatment. After final treatment, athletes with metatarsal fractures were casted for 6 weeks, and all athletes were instructed to rest for 6–8 weeks. Repeat imaging at 6–14 weeks revealed bony fusion in all athletes. Over a span of 3–10 months post-treatment, all athletes were able to return to sport without pain or functional limitation. These results were similar to an earlier 2007 report by Taki et al. in 5 athletes with delayed union or non-union of stress fractures, including anterior tibia cortex ($n = 2$), and one of each in 5th metatarsal, inferior pubic ramus, and medial malleolous [32]. Athletes were four men and one woman participating in baseball, basketball, soccer, and marathon running. All underwent one session of high-energy F-SWT under spinal anesthesia, followed by casting for 4 weeks for two athletes with pseudoarthroses and rest for others. After an average of 2.9 months, bony fusion was demonstrated on repeat imaging in all cases. All athletes returned to sport after an average of 4 months [32].

Osteitis Pubis

A single study conducted by Schöberl et al. in 2017 was identified on the use of ESWT to treat osteitis pubis in 95 amateur male soccer players [47•]. This study included a RCT arm comparing F-SWT with sham ESWT with shockwave-blocking head with both groups undergoing an intensive rehabilitation program. A separate prospective cohort arm included sport limitation only. At 1 and 3 months, the F-SWT group had improved VAS pain and functional capability as assessed by the hip disability and osteoarthritis outcome score (HOOS) compared with the sham SWT group. The F-SWT group had earlier return to play time compared with the sham SWT group, 2.5 vs 3.5 months, respectively. Within 4 months, 95% of the players in the RCT arm (receiving either F-SWT or sham SWT) had returned to sport with no instances of recurrent groin pain at 1 year. Comparatively, athletes in the prospective cohort arm undergoing sport limitation strategies only returned to sport at 8 months with 51% experiencing symptom recurrence. This condition typically portends extended debility with return to prior level of sport averaging 9.5 months in male and 7 months in female athletes [48]. Thus, the intensive, three-phase, multi-modal rehabilitation program included in this study protocol appears to have independent benefit in allowing earlier return to play, though effect from sham therapy cannot be excluded, particularly because EFD was not reported for either F-SWT or sham ESWT group.

Adverse Effects

ESWT is a safe treatment option with common side effects including pain during the procedure and transient skin redness, reported in approximately 20% of participants undergoing ESWT for plantar fasciitis [49]. Other far less common side effects include bruising, swelling, dysesthesia, and pain lasting up to 1 week after treatment [49]. Notably, one reported case of plantar fascia rupture was reported during treatment; the injury appeared to be self-limited as she was able to return to her sport 6 weeks following injury [18•]. The remaining studies reviewed did not report any major complications attributed to the treatment of lower extremity conditions, including secondary injury or tendon rupture. Additional considerations should include potential out-of-pocket costs to the patient, as well as the need for concomitant physical therapy and other conservative management strategies in order to optimize treatment response.

Future Research Considerations

This review identified limited articles investigating applications of ESWT in lower extremity sports injuries. Despite the relative paucity of studies, a promising trend is observed in the quality of study design over the past decade. Of the 10 identified RCTs, four were conducted since 2017, and eight since 2011. Generalizability of much of the current body of literature is hampered by heterogeneity in subject populations, low sample sizes, lack of true control groups, and widely variable treatment protocols. In general, female athletes are underrepresented among study populations, and no studies to date have included adaptive athletes. Of the 22 included studies, 17 treated athletes with F-SWT compared with 5 with R-SWT. There was no particular pattern in the type of shockwave selected based on diagnosis. Given the wide range of total number of sessions, frequency of treatment, number of pulses per session, and EFD, we reported total cumulative dose when possible to help facilitate comparison among studies. Given demonstrated placebo effect of sham SWT [50], future research must clarify lowest effective dose when using sham SWT so as not to exceed this value and create a therapeutic effect in control groups. Additionally, post-treatment management was not consistent. Studies including rest with graded return to sport may have overlooked potential early benefits of ESWT as athletes can typically continue sport participation and training during treatment. This is in contrast with regenerative injectable or surgical alternatives. Development of standardized ESWT and post-treatment protocols based on diagnosis are needed to help guide future randomized controlled trials, better facilitate outcome comparisons, and further elucidate the role for ESWT in the athletic population.

Conclusions

There is limited yet growing evidence to support the use of ESWT for pain relief and functional benefit in common lower extremity sports injuries, including plantar fasciitis, patellar tendinopathy, Achilles tendinopathy, and medial tibial stress syndrome. Given the non-invasive nature of this treatment, good safety profile, and ability to continue sport participation for most conditions, ESWT may be considered when athletes fail to improve with more conservative interventions. Future research should be focused on developing more standardized, evidence-based ESWT treatment protocols for management of specific athletic injuries.

Compliance with Ethical Standards

Conflict of Interest Amol Saxena reports personal fees and non-financial support from Storz/Curamedix outside the submitted work. Haylee Borgstrom and Adam Tenforde declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance

1. Maffulli G, Padulo J, Iuliano E, Saxena A, Rompe J, Maffulli N. Extracorporeal shock wave therapy in the treatment of midsubstance Achilles tendinopathy: the ASSERT database. Muscles Ligaments Tendons J. 2018;8(3):409–15.
2. Maffulli G, Padulo J, Iuliano E, Saxena A, Rompe J, Maffulli N. Extracorporeal shock wave therapy in the treatment of insertional Achilles tendinopathy: the ASSERT database. Muscles Ligaments Tendons J. 2018;8(3):416–22.
3. Vulpiani MC, Trischitta D, Trovato P, Vetrano M, Ferretti A. Extracorporeal shockwave therapy (ESWT) in Achilles tendinopathy. A long-term follow-up observational study. J Sports Med Phys Fitness. 2009;49(2):171–6.
4. Furia JP. High-energy extracorporeal shock wave therapy as a treatment for chronic noninsertional Achilles tendinopathy. Am J Sports Med. 2008;36(3):502–8.
5. 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;79(2):249–56.
6. 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;90(1):52–61.
7. Furia JP. High-energy extracorporeal shock wave therapy as a treatment for insertional Achilles tendinopathy. Am J Sports Med. 2006;34(5):733–40.
8. Maffulli G, Padulo J, Iuliano E, Furia J, Rompe J, Maffulli N. Extracorporeal shock wave therapy in the treatment of patellar tendinopathy: the ASSERT database. Muscles Ligaments Tendons J. 2018;8(3):437–43.
9.• Thijs KM, Zwerver J, Backx FJ, Steeneken V, Rayer S, Groenenboom P, et al. Effectiveness of shockwave treatment combined with eccentric training for patellar tendinopathy: a double-blinded randomized study. Clin J Sport Med. 2017;27(2):89–96 **This RCT of 52 active adults with patellar tendinopathy for 2 or more months found no difference in pain or sport function up to 24 weeks after focused SWT plus eccentric exercise compared to sham SWT plus eccentric exercise. This study is limited by lack of true control group to account for potential therapeutic effect of sham SWT.**
10. Vetrano M, Castorina A, Vulpiani MC, Baldini R, Pavan A, Ferretti A. Platelet-rich plasma versus focused shock waves in the treatment of jumper's knee in athletes. Am J Sports Med. 2013;41(4):795–803.
11. 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;47(3):323–8.
12. Peers KH, Lysens RJ, 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;13(2):79–83.

13. Cacchio A, Rompe JD, Furia JP, Susi P, Santilli V, De Paulis F. Shockwave therapy for the treatment of chronic proximal hamstring tendinopathy in professional athletes. Am J Sports Med. 2011;39(1):146–53.
14. Maffulli G, Padulo J, Iuliano E, Furia J, Rompe J, Maffulli N. Extracorporeal shock wave therapy in the treatment of trochanteric bursitis: the ASSERT database. Muscles Ligaments Tendons J. 2018;8(3):444–50.
15. 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.
16. 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.
17. Maffulli G, Padulo J, Iuliano E, Furia J, Rompe J, Maffulli N. Extracorporeal shock wave therapy in the treatment of midsubstance plantar fasciitis: the ASSERT database. Muscles Ligaments Tendons J. 2018;8(3):430–6.
18.• Saxena A, Hong BK, Yun AS, Maffulli N, Gerdesmeyer L. Treatment of plantar fasciitis with radial soundwave "early" is better than after 6 months: a pilot study. J Foot Ankle Surg. 2017;56(5):950–3 **This prospective cohort of 28 participants (71% recreational athletes) with plantar fasciitis found improved pain and treatment success scores both in those with symptoms for less than 3 months and those with symptoms for longer than 6 months after radial SWT, suggesting potential use as an early treatment option. This study is limited by lack of control group.**
19. Gollwitzer H, Saxena A, DiDomenico LA, Galli L, Bouche RT, Caminear DS, et al. 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;97(9):701–8.
20. 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;24(Pt B): 135–42.
21. 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. 2012;2(4): 312–6.
22. Kudo P, Dainty K, Clarfield M, Coughlin L, Lavoie P, Lebrun C. Randomized, placebo-controlled, double-blind clinical trial evaluating the treatment of plantar fasciitis with an extracoporeal shockwave therapy (ESWT) device: a North American confirmatory study. J Orthop Res. 2006;24(2):115–23.
23. Moretti B, Garofalo R, Patella V, Sisti GL, Corrado M, Mouhsine E. Extracorporeal shock wave therapy in runners with a symptomatic heel spur. Knee Surg Sport Traumatol Arthrosc. 2006;14(10):1029–32.
24. Rompe JD, Decking J, Schoellner C, Nafe B. Shock wave application for chronic plantar fasciitis in running athletes. A prospective, randomized, placebo-controlled trial. Am J Sports Med. 2003;31(2):268–75.
25. Saxena A, Fullem B, Gerdesmeyer L. Treatment of medial tibial stress syndrome with radial soundwave therapy in elite athletes: current evidence, report on two cases, and proposed treatment regimen. J Foot Ankle Surg. 2017;56(5):985–9.
26. Moen MH, Rayer S, Schipper M, Schmikli S, Weir A, Tol JL, et al. Shockwave treatment for medial tibial stress syndrome in athletes; a prospective controlled study. Br J Sports Med. 2012;46(4):253–7.
27. Rompe JD, Cacchio A, Furia JP, Maffulli N. Low-energy extracorporeal shock wave therapy as a treatment for medial tibial stress syndrome. Am J Sports Med. 2010;38(1):125–32.
28. 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;24(Pt B):131–4.
29. Cacchio A, Giordano L, Colafarina O, Rompe JD, Tavernese E, Ioppolo F, et al. Extracorporeal shock-wave therapy compared with surgery for hypertrophic long-bone nonunions. J Bone Joint Surg Am. 2009;91(11):2589–97.
30. Moretti B, Notarnicola A, Garofalo R, Moretti L, Patella S, Marlinghaus E, et al. Shock waves in the treatment of stress fractures. Ultrasound Med Biol. 2009;35(6):1042–9.
31. Xu ZH, Jiang Q, Chen DY, Xiong J, Shi DQ, Yuan T, et al. Extracorporeal shock wave treatment in nonunions of long bone fractures. Int Orthop. 2009;33(3):789–93.
32. Taki M, Iwata O, Shiono M, Kimura M, Takagishi K. Extracorporeal shock wave therapy for resistant stress fracture in athletes: a report of 5 cases. Am J Sports Med. 2007;35(7):1188–92.
33. Korakakis V, Whiteley R, Tzavara A, Malliaropoulos N. The effectiveness of extracorporeal shockwave therapy in common lower limb conditions: a systematic review including quantification of patient-rated pain reduction. Br J Sports Med. 2018;52(6):387–407.
34. Reilly JM, Bluman E, Tenforde AS. Effect of shockwave treatment for management of upper and lower extremity musculoskeletal conditions: a narrative review. PM R. 2018;10(12):1385–403.
35. 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;43(3): 752–61.
36. Moya D, Ramon S, Schaden W, Wang CJ, Guiloff L, Cheng JH. The role of extracorporeal shockwave treatment in musculoskeletal disorders. J Bone Joint Surg Am. 2018;100(3):251–63.
37. Peters J, Luboldt W, Schwarz W, Jacobi V, Herzog C, Vogl TJ. Extracorporeal shock wave therapy in calcific tendinitis of the shoulder. Skelet Radiol. 2004;33(12):712–8.
38. Klonschinski T, Ament SJ, Schlereth T, Rompe JD, Birklein F. Application of local anesthesia inhibits effects of low-energy extracorporeal shock wave treatment (ESWT) on nociceptors. Pain Med. 2011;12(10):1532–7.
39. Wang CJ, Wang FS, Yang KD, Weng LH, Hsu CC, Huang CS, et al. Shock wave therapy induces neovascularization at the tendon-bone junction. A study in rabbits. J Orthop Res. 2003;21(6):984–9.
40. Waugh CM, Morrissey D, Jones E, Riley GP, Langberg H, Screen HR. In vivo biological response to extracorporeal shockwave therapy in human tendinopathy. Eur Cells Mater. 2015;29:268–80 discussion 80.
41. Vetrano M, d'Alessandro F, Torrisi MR, Ferretti A, Vulpiani MC, Visco V. Extracorporeal shock wave therapy promotes cell proliferation and collagen synthesis of primary cultured human tenocytes. Knee Surg Sports Traumatol Arthrosc. 2011;19(12): 2159–68.
42. 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.
43.• Gomez Garcia S, Ramon Rona S, Gomez Tinoco MC, Benet Rodriguez M, Chaustre Ruiz DM, Cardenas Letrado FP, et al. Shockwave treatment for medial tibial stress syndrome in military cadets: a single-blind randomized controlled trial. Int J Surg. 2017;46:102–9 **This RCT of 42 military cadets with MTSS for 3 or more months found reduced pain and improved running duration after a single session of focused SWT and exercise program compared to exercise program alone.**
44.• Newman P, Waddington G, Adams R. Shockwave treatment for medial tibial stress syndrome: a randomized double blind sham-

controlled pilot trial. J Sci Med Sport. 2017;20(3):220–4 **This RCT of 28 active adults with MTSS for 3 or more months found no clinically significant difference in pain or sport function at 10 weeks after focused SWT compared to sham SWT. This study is limited by short follow-up duration and lack of true control group to account for potential therapeutic effect of sham SWT.**

45. 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;39(6):1191–9.

46. Rompe JD, Meurer A, Nafe B, Hofmann A, Gerdesmeyer L. Repetitive low-energy shock wave application without local anesthesia is more efficient than repetitive low-energy shock wave application with local anesthesia in the treatment of chronic plantar fasciitis. J Orthop Res. 2005;23(4):931–41.

47.• Schoberl M, Prantl L, Loose O, Zellner J, Angele P, Zeman F, et al. Non-surgical treatment of pubic overload and groin pain in amateur football players: a prospective double-blinded randomised controlled study. Knee Surg Sports Traumatol Arthrosc. 2017;25(6):1958–66 **This RCT of 95 amateur male soccer players with osteitis pubis found earlier return to sport, reduced pain, and improved sport function at 1 and 3 months after focused SWT with rehabiliation program compared to sham SWT with rehabilitation program.**

48. Fricker PA, Taunton JE, Ammann W. Osteitis pubis in athletes. Infection, inflammation or injury? Sports Med. 1991;12(4):266–79.

49. Roerdink RL, Dietvorst M, van der Zwaard B, van der Worp H, Zwerver J. Complications of extracorporeal shockwave therapy in plantar fasciitis: systematic review. Int J Surg. 2017;46:133–45.

50. Gerdesmeyer L, Klueter T, Rahlfs VW, Muderis MA, Saxena A, Gollwitzer H, et al. Randomized placebo-controlled placebo trial to determine the placebo effect size. Pain Phys. 2017;20(5):387–96.