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Case Report

The Effectiveness of Radial Extracorporeal Shock Wave Therapy for Chronic Achilles Tendinopathy: A Case Report with 18 Months Follow-Up

Erieta Dimitrije Nikolikj–Dimitrova*, Cvetanka Gjerakaroska-Savevska, Valentina Koevska, Biljana Mitrevska, Marija Gocevska, Maja Manoleva, Biljana Kalchovska-Ivanovska

Institute of Physical Medicine and Rehabilitation, Faculty of Medicine, Ss Cyril and Methodius University of Skopje, Skopje, Republic of Macedonia

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Keywords: Achilles tendinopathy; extracorporeal shock wave therapy; long-term outcome; heel pain

***Correspondence:** Erieta Dimitrije Nikolikj–Dimitrova, Institute of Physical Medicine and Rehabilitation, Faculty of Medicine, "Ss Cyril and Methodius "University, Skopje, Republic of Macedonia. E-mail: erietand@yahoo.com

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Abstract

BACKGROUND: Achilles tendinopathy (AT) is a pathological state resulting from repetitive loading or stress on the tendon. The article aims to evaluate the effects of the low - energy radial extracorporeal shockwave therapy (RESWT) in the treatment of the adult with chronic insertional Achilles tendinopathy (AT) after the unsuccessful conservative treatment, with 18 months follow - up evaluation.

CASE REPORT: We report the case of a 55 years - old male suffering from severe right posterior heel pain for 4 months. For his chronic insertional Achilles tendinopathy on the right heel, he received conservative treatment in the Institute of Physical Medicine and Rehabilitation. For outcome assessment, Numerical Rating Scale (NRS) for pain, the range of motion in the ankle, and Roles-Maudsley Score (RMS) for assessment of function were used. At the baseline the pain was severe, and he received physical therapy treatment. After unsuccessful conservative treatment, he underwent RESWT treatment. Numeric Rating Scale was significantly decreased at immediate, short-term and long-term follow-up. After the last treatment, the patient had no pain, and function assessed by Roles-Maudsley Score was excellent. At the follow-up check-up at 3, 6, 12 and 18 months the patient had no pain and excellent functional results.

CONCLUSION: Radial ESWT is a safe and effective treatment even for a longer period for patients with chronic insertional Achilles tendinopathy.

Introduction

Achilles tendinopathy (AT) is a pathological state resulting from repetitive loading or stress on the tendon [1]. The two main categories of Achilles tendon disorder are broadly classified by anatomical location to include non - insertional and insertional conditions [2].

This clinical condition is characterised by pain and tenderness in or around Achilles tendon, frequently occurring in active, as well as, inactive individuals [3]. Chronic Achilles tendinopathy was defined as a condition lasting more than six weeks [4] or more than three months [1]. Chronic Achilles tendinopathy has been described as the most common overuse injury in sports medicine [5].

Several treatment modalities such as activity modification, heel lifts, arch supports, stretching exercises, nonsteroidal anti-inflammatories, and eccentric loading are known as standard conservative treatment [4] [5] [6], as well as various injections and extracorporeal shock wave therapy (ESWT) [2].

In chronic refractory cases that exhibited no improvement after appropriate conservative treatment, surgical intervention has been performed [5] [6] [7].

Extracorporeal shock wave therapy (ESWT) has been successfully used in soft - tissue pathologies like lateral epicondylitis, plantar fasciitis, and calcific

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RESEARCH ARTICLE Open Access

Individualised radial extracorporeal shock wave therapy (rESWT) for symptomatic calcific shoulder tendinopathy: a retrospective clinical study

Nikolaos Malliaropoulos[1,2,3,4,5], Dawn Thompson[6*], Maria Meke[1,2], Debasish Pyne[4,5], Dimosthenis Alaseirlis[2,7], Henry Atkinson[8,9], Vasileios Korakakis[10,11,12] and Heinz Lohrer[13,14]

Abstract

Background: A retrospective single centre cohort analysis was performed to evaluate an individualised radial extracorporeal shock wave therapy (rESWT) protocol for treatment of symptomatic calcific shoulder tendinopathy.

Methods: 67 patients (79 Shoulders) were identified with 76 shoulders included for analysis. rESWT treatment protocol was adapted according to individual response to treatment. Variables included number of sessions, shockwave impulses, pressure and frequency. Success rate was estimated as the percentage of patients having ≥60% visual analogue score (VAS) pain decrease at follow-up. Recurrence at 1 year was recorded.

Results: Using this individualised symptom guided protocol, patients underwent a mean of 7 ± 1.5 rESWT sessions, with mean pressure of 1.7 ± 0.2 bar, mean frequency of 5 ± 0.3 Hz and 2175 ± 266 impulses. The mean pre-treatment VAS score of 6.7 ± 1.1 was significantly decreased to 3.2 ± 0.8 immediately post-treatment, 2.6 ± 0.9 at 1 month, 1.7 ± 1.0 at 3 months and 0.8 ± 1.0 at 1 year follow up ($\alpha = 0.05$). One-year success rate was estimated at 92% and 1-year recurrence rate was 7%.

Conclusions: We conclude that in this retrospective study an individualised rESWT protocol resulted in a high success rate with low number of recurrences. Randomised controlled trials to support these findings are recommended.

Keywords: ESWT, Radial extracorporeal shockwave therapy, Recurrence rate, Symptomatic shoulder calcifying tendinopathy, Treatment

Background

Symptomatic calcifying tendinopathy of the shoulder is a common condition characterised by the accumulation of calcium hydroxyapatite crystals within the tendons of the rotator cuff muscles [1].

The condition often presents acutely, though can be sub-acute or chronic [2]. The natural history of the disease is unclear, some consider it to be self-limiting though others report a protracted clinical course resulting in significant disability [3, 4]. Calcification is most commonly found within the proximal supraspinatous tendon at the 'critical zone,' an area of tendon at risk of tissue hypoxia [5–8]. The degenerative process may occur due to an impingement syndrome, poor blood supply, increased stress on the tendon and/or anatomical variations of the acromion [4, 9]. Typical features of symptomatic calcific shoulder tendinopathy include pain and temporary loss of function which can be severe and is worse during shoulder abduction [8, 10]. Clinical findings often include local tenderness usually with mechanical block and occasional crepitus; radiographically detectable calcification near the rotator cuff insertion is also seen [11, 12].

During the acute phase, lasting 3 weeks - 6 months, pain is severe due to an aggressive inflammatory response. The

* Correspondence: dawnthompson@doctors.org.uk
[6]Imperial College School of Medicine, Imperial College, London, UK
Full list of author information is available at the end of the article

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RESEARCH ARTICLE Open Access

Radial extracorporeal shock wave therapy is efficient and safe in the treatment of fracture nonunions of superficial bones: a retrospective case series

Paulo Kertzman[1], Nikolaus B. M. Császár[2], John P. Furia[3] and Christoph Schmitz[2*]

Abstract

Background: A substantial body of evidence supports the use of focused extracorporeal shock wave therapy (fESWT) in the non-invasive treatment of fracture nonunions. On the other hand, virtually no studies exist on the use of radial extracorporeal shock wave therapy (rESWT) for this indication.

Methods: We retrospectively analyzed 22 patients treated with rESWT for fracture nonunions of superficial bones that failed to heal despite initial surgical fixation in most cases. Radial extracorporeal shock wave therapy was applied without anesthesia in three rESWT sessions on average, with one rESWT session per week and 3000 radial extracorporeal shock waves at an energy flux density of 0.18 mJ/mm^2 per session. Treatment success was monitored with radiographs and clinical examinations.

Results: Six months after rESWT radiographic union was confirmed in 16 out of 22 patients (73%), which is similar to the success rate achieved in comparable studies using fESWT. There were no side effects. The tibia was the most common treatment site (10/22) and 70% of tibia nonunions healed within 6 months after rESWT. Overall, successfully treated patients showed a mean time interval of 8.8 ± 0.8 (mean ± standard error of the mean) months between initial fracture and commencement of rESWT whereas in unsuccessfully treated patients the mean interval was 26.0 ± 10.1 months ($p < 0.05$). In unsuccessful tibia cases, the mean interval was 43.3 ± 13.9 months.

Conclusions: Radial extracorporeal shock wave therapy appears to be an effective and safe alternative in the management of fracture nonunions of superficial bones if diagnosed early and no fESWT device is available. The promising preliminary results of the present case series should encourage the implementation of randomized controlled trials for the early use of rESWT in fracture nonunions.

Keywords: Bone, Focused extracorporeal shock wave therapy, Fracture, Nonunion, Radial extracorporeal shock wave therapy

Background

Nonunion refers to the failure of bone fractures to achieve cortical continuity on radiographic studies. The prevalence of nonunion of all fracture types ranges from 2.5 to 46%, and the complication places substantial economic burdens on health systems [1–3]. Surgical fracture stabilization using bone grafts and internal/external fixation has remained the gold standard for treating fracture nonunions. However, these procedures often lead to serious complications including deep infections, persistent wound drainage, hematoma formation, sensory loss, persisting pain, and nonunions [2, 4–6].

Hence, there remains a need for efficient therapies that will bring better results more quickly and without major complications. Over the past decades, extracorporeal shock wave therapy (ESWT) has emerged as an efficient, non-invasive and cost-effective alternative to surgery in

* Correspondence: christoph_schmitz@med.uni-muenchen.de
[2]Extracorporeal Shock Wave Research Unit, Chair of Neuroanatomy, Institute of Anatomy, Faculty of Medicine, LMU Munich, Pettenkoferstr 11, D-80336 Munich, Germany
Full list of author information is available at the end of the article

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Radial Extracorporeal Shock Wave Therapy Is Safe and Effective in the Treatment of Chronic Recalcitrant Plantar Fasciitis

Results of a Confirmatory Randomized Placebo-Controlled Multicenter Study

Ludger Gerdesmeyer,*†‡ MD, PhD, Carol Frey,§ MD, Johannes Vester,‖ PhD, Markus Maier,¶ PhD, Lowell Weil Jr,# DPM, Lowell Weil Sr,# DPM, Martin Russlies,** PhD, John Stienstra,†† DPM, Barry Scurran,†† DPM, Keith Fedder,§ MD, Peter Diehl,‡‡ MD, Heinz Lohrer,§§ MD, Mark Henne,† MD, and Hans Gollwitzer,† MD

*From the †Department of Orthopedic and Traumatology, Technical University Munich, Klinikum Rechts der Isar, Germany, the ‡Department of Joint Arthroplasty and Clinical Science, Mare Clinic, Kiel, Germany, §Orthopaedic Foot and Ankle Center, Manhattan Beach, California, ‖IDV Data Analyses and Study Planning, Biometrics in Medicine, Gauting, Germany, the ¶Department of Orthopedics, Ludwig Maximilian University, Munich, Germany, the #Weil Foot and Ankle Institute, Des Plaines, Illinois, **University Schleswig Holstein, Campus Lübeck, Lübeck, Germany, the ††Department of Podiatry, The Permanente Medical Group Inc, Union City, California, the ‡‡Department of Orthopedics, University Rostock, Rostock, Germany, and the §§Institute of Sportsmedicine, Frankfurt am Main, Germany*

Background: Radial extracorporeal shock wave therapy is an effective treatment for chronic plantar fasciitis that can be administered to outpatients without anesthesia but has not yet been evaluated in controlled trials.

Hypothesis: There is no difference in effectiveness between radial extracorporeal shock wave therapy and placebo in the treatment of chronic plantar fasciitis.

Study Design: Randomized, controlled trial; Level of evidence, 1.

Methods: Three interventions of radial extracorporeal shock wave therapy (0.16 mJ/mm^2; 2000 impulses) compared with placebo were studied in 245 patients with chronic plantar fasciitis. Primary endpoints were changes in visual analog scale composite score from baseline to 12 weeks' follow-up, overall success rates, and success rates of the single visual analog scale scores (heel pain at first steps in the morning, during daily activities, during standardized pressure force). Secondary endpoints were single changes in visual analog scale scores, success rates, Roles and Maudsley score, SF-36, and patients' and investigators' global judgment of effectiveness 12 weeks and 12 months after extracorporeal shock wave therapy.

Results: Radial extracorporeal shock wave therapy proved significantly superior to placebo with a reduction of the visual analog scale composite score of 72.1% compared with 44.7% ($P = .0220$), and an overall success rate of 61.0% compared with 42.2% in the placebo group ($P = .0020$) at 12 weeks. Superiority was even more pronounced at 12 months, and all secondary outcome measures supported radial extracorporeal shock wave therapy to be significantly superior to placebo ($P < .025$, 1-sided). No relevant side effects were observed.

Conclusion: Radial extracorporeal shock wave therapy significantly improves pain, function, and quality of life compared with placebo in patients with recalcitrant plantar fasciitis.

Keywords: heel pain; plantar fasciitis; shock wave; lithotripsy; radial extracorporeal shock wave therapy

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Low-Energy Extracorporeal Shock Wave Therapy as a Treatment for Medial Tibial Stress Syndrome

Jan D. Rompe,*† MD, Angelo Cacchio,‡ MD, John P. Furia,§ MD, and Nicola Maffulli,‖ MD, MS, PhD, FRCS(Orth), FFSEM(UK)

From †OrthoTrauma Evaluation Center, Mainz, Germany, the ‡Department of Medicine and Physical Rehabilitation, San Salvatore Hospital of L'Aquila, Italy, §SUN Orthopaedics, Lewisburg, Pennsylvania, and the ‖Centre for Sports and Exercise Medicine, Barts, and The London School of Medicine and Dentistry, London, England

Background: Medial tibial stress syndrome (MTSS) is a pain syndrome along the tibial origin of the tibialis posterior or soleus muscle. Extracorporeal shock wave therapy (SWT) is effective in numerous types of insertional pain syndromes.

Hypothesis: Shock wave therapy is an effective treatment for chronic MTSS.

Study Design: Cohort study; Level of evidence, 3.

Methods: Forty-seven consecutive subjects with chronic recalcitrant MTSS underwent a standardized home training program, and received repetitive low-energy radial SWT (2000 shocks; 2.5 bars of pressure, which is equal to 0.1 mJ/mm^2; total energy flux density, 200 mJ/mm^2; no local anesthesia) (treatment group). Forty-seven subjects with chronic recalcitrant MTSS were not treated with SWT, but underwent a standardized home training program only (control group). Evaluation was by change in numeric rating scale. Degree of recovery was measured on a 6-point Likert scale (subjects with a rating of completely recovered or much improved were rated as treatment success).

Results: One month, 4 months, and 15 months from baseline, success rates for the control and treatment groups according to the Likert scale were 13% and 30% ($P < .001$), 30% and 64% ($P < .001$), and 37% and 76% ($P < .001$), respectively. One month, 4 months, and 15 months from baseline, the mean numeric rating scale for the control and treatment groups were 7.3 and 5.8 ($P < .001$), 6.9 and 3.8 ($P < .001$), and 5.3 and 2.7 ($P < .001$), respectively. At 15 months from baseline, 40 of the 47 subjects in the treatment group had been able to return to their preferred sport at their preinjury level, as had 22 of the 47 control subjects.

Conclusion: Radial SWT as applied was an effective treatment for MTSS.

Keywords: tendon injuries; medial tibial stress syndrome; shin splints; shock wave therapy

Shin splints—referring to pain and discomfort in the leg from repetitive running on hard surfaces or forcible excessive use of foot flexors—accounts for 6% to 16% of all running injuries and is responsible for as much as 50% of all lower leg injuries reported in select populations.¶ Alternative terms to shin splints have been proposed over the years. Mubarak et al[42] popularized the term *medial tibial stress syndrome* (MTSS), a condition that leads to pain in the posteromedial aspect of the distal two thirds of the tibia.

A diagnosis of MTSS specifically excludes exertional compartment syndrome and tibial stress fracture. It offers the most accurate description of the involved anatomy and presumed pathophysiology of this most common form of tibial stress injury.[15] The hallmark of the physical examination in MTSS is palpable tenderness over a 4- to 6-cm area at the posteromedial margin of the middle to distal third of the tibia.[3,11,26,35,41,68] Range of motion of the ankle and foot should not elicit pain. Passive stretch of the soleus, heel rises, and unilateral hopping may reproduce symptoms. Vascular and neurologic examinations produce normal results in subjects with MTSS.[44]

*Address correspondence to Jan D. Rompe, MD, OrthoTrauma Evaluation Center, Oppenheimer Street 70, D-55130 Mainz, Germany (e-mail: profrompe@web.de).

No potential conflict of interest declared.

¶References 10, 11, 29, 30, 34, 35, 45, 60, 61, 69.

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RESEARCH ARTICLE Open Access

Comparison of single-dose radial extracorporeal shock wave and local corticosteroid injection for treatment of carpal tunnel syndrome including mid-term efficacy: a prospective randomized controlled trial

Pichitchai Atthakomol[1*], Worapaka Manosroi[2], Areerak Phanphaisarn[1], Sureeporn Phrompaet[1], Sawan Iammatavee[3] and Siam Tongprasert[4]

Abstract

Background: Recent studies have reported that radial extracorporeal shock wave therapy (rESWT) reduces pain and improves function in patients with mild to moderately severe carpal tunnel syndrome (CTS) compared to a placebo. However, most of those studies used multi-session rESWT combined with wrist support and evaluation of efficacy was limited to a maximum of 14 weeks.

Methods: The prospective randomized controlled trial compared efficacy in relieving pain and improving clinical function between single-dose rESWT and local corticosteroid injection (LCsI) over the mid-term (24 weeks). Twenty-five patients with mild to moderately severe CTS were randomized to receive either single-dose rESWT ($n = 13$) or LCsI ($n = 12$). Primary outcomes were evaluated using the Boston self-assessment questionnaire (BQ), while secondary outcomes used the Visual analogue scale (VAS) and electrodiagnostic parameters. Evaluations at baseline and at 1, 4, 12 and 24 weeks after treatment were performed.

Results: There was significantly greater improvement in symptom severity scores, functional scores and Boston questionnaire scores at weeks 12 to 24 in the rESWT group compared to the LCsI group. When compared to the baseline, there was significant reduction of VAS and functional score in the rESWT group at weeks 12 and 24. The LCsI group had no statistically significant differences in VAS reduction and functional score of the same period.

Conclusions: Treatment of CTS using single-dose rESWT has a carry-over effect lasting up to 24 weeks suggesting that single-dose rESWT is appropriate for treatment of mild to moderate CTS and provides longer-lasting benefits than LCsI.

Trial registration: (TCTR20150709001). Registered 9 July 2015

Keywords: Extracorporeal shock wave, Steroid injection, Carpal tunnel syndrome, Randomized controlled trial, Treatment

* Correspondence: p.atthakomol@gmail.com
[1]Department of Orthopaedics, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand
Full list of author information is available at the end of the article

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CLINICAL TRIAL/EXPERIMENTAL STUDY

OPEN

Effect of Radial Shock Wave Therapy on Spasticity of the Upper Limb in Patients With Chronic Stroke

A Prospective, Randomized, Single Blind, Controlled Trial

Tsung-Ying Li, MD, Chih-Ya Chang, MD, Yu-Ching Chou, PhD, Liang-Cheng Chen, MD, MS, Heng-Yi Chu, MD, Shang-Lin Chiang, MD, MS, Shin-Tsu Chang, MD, MS, PhD, and Yung-Tsan Wu, MD

Abstract: Recently, studies have reported that extracorporeal shock wave therapy (ESWT) is a safe, noninvasive, alternative treatment for spasticity. However, the effect of ESWT on spasticity cannot be determined, because most studies to date have enrolled small patient numbers and have lacked placebo-controlled groups and/or long-term follow-up. In addition, whether varying the number of ESWT sessions would affect the duration of the therapeutic effect has not been investigated in a single study. Hence, we performed a prospective, randomized, single blind, placebo-controlled study to investigate the long-term effect of radial ESWT (rESWT) in patients with poststroke spasticity and surveyed the outcome of functional activity.

Sixty patients were randomized into 3 groups. Group A patients received 1 session of rESWT per week for 3 consecutive weeks; group B patients received a single session of rESWT; group C patients received one session of sham rESWT per week for 3 consecutive weeks. The primary outcome was Modified Ashworth Scale of hand and wrist, whereas the secondary outcomes were Fugl-Meyer Assessment of hand function and wrist control. Evaluations were performed before the first rESWT treatment and immediately 1, 4, 8, 12, and 16 weeks after the last session of rESWT.

Compared to the control group, the significant reduction in spasticity of hand and wrist lasted at least 16 and 8 weeks in group A and B, respectively. Three sessions of rESWT had a longer-lasting effect than one session. Furthermore, the reduction in spasticity after 3 sessions of rESWT may be beneficial for hand function and wrist control and the effect was maintained for 16 and 12 weeks, respectively.

rESWT may be valuable in decreasing spasticity of the hand and wrist with accompanying enhancement of wrist control and hand function in chronic stroke patients.

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From the Department of Physical Medicine and Rehabilitation (T-YL, C-YC, L-CC, H-YC, S-LC, S-TC, Y-TW), Tri-Service General Hospital, School of Medicine; School of Public Health, National Defense Medical Center (Y-CC), Neihu District, Taipei; Department of Physical Medicine and Rehabilitation (L-CC), Hualien Armed Forces General Hospital, Hualien County; and Department of Rehabilitation (S-TC), Taichung Veterans General Hospital, Taiwan Boulevard, Taichung, Taiwan, Republic of China.
Correspondence: Yung-Tsan Wu, Department of Physical Medicine and Rehabilitation, Tri-Service General Hospital, School of Medicine, National Defense Medical Center, No. 325, Sec. 2, Cheng-Kung Road, Neihu District, Taipei, Taiwan, Republic of China (e-mail: crwu98@gmail.com).
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Abbreviations: ANOVA = analysis of variance, BTX = botulinum toxin, ESWT = extracorporeal shock wave therapy, fESWT = focused ESWT, FMA = Fugl-Meyer Assessment, MAS = Modified Ashworth Scale, NO = nitric oxides, rESWT = radial ESWT, ROM = range of motion.

INTRODUCTION

Extracorporeal shock wave therapy (ESWT) is defined as a sequence of acoustic pulses characterized by high peak pressure (100 MPa), fast pressure rise (<10 ns), short duration (10 μs), and an energy density ranging from 0.003 to 0.890 mJ/mm.[1] Different studies and clinical experiments have demonstrated the efficacy of ESWT in the treatment of musculoskeletal disorders such as chronic tendinopathies, calcific tendinitis of the shoulder, lateral epicondylitis, and plantar fasciitis, etc.[1] The side effects of ESWT including aching, tingling, redness, or bruising are relatively rare and transitory.[1]

Radial ESWT (rESWT), a type of pneumatically generated shock wave, has a low to medium energy compared with traditional focused ESWT (fESWT). These unforced shock waves disperse eccentrically from the applicator tip without focusing the energy to a targeted spot. The penetrative depth is therefore less than that of fESWT (up to 3 vs 12 cm).[2] A recent systematic review and meta-analysis reported potential advantages of rESWT over fESWT in patients with plantar fasciitis because rESWT has a larger treatment area, specific focusing is less important, it does not require additional local anesthesia, and it is cheaper.[2]

Spasticity is a common complication in patients with stroke and is defined as a velocity-dependent enhancement in muscle tone in response to passive stretching because of supraspinal disinhibition of stretch reflexes. The prevalence of spasticity is reported as 39% in patients with 1st-ever stroke after 12 months.[3] The constant contraction of spastic muscles can produce pain, declined mobility, contractures, and skeletal deformities, which may limit the potential effect of rehabilitation.[4] Common management of spasticity consists of passive stretching, splints, drug, phenol injection, and botulinum toxin (BTX) injection. However, current treatments of spasticity in poststroke survivors are often unsatisfactory.[5]

In recent years, studies have reported that ESWT is a safe, noninvasive, alternative treatment for spasticity that does not cause muscle weakness or unpleasant effects in patients with stroke,[6–15] cerebral palsy,[16–19] and multiple sclerosis.[20] Although a recent small meta-analysis (including only 5 studies) reported that ESWT had a significant effect on improving spasticity 4 weeks after treatment compared with baseline in patients with brain injury,[21] the effect of ESWT on spasticity

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RESEARCH ARTICLE Open Access

Exposure to radial extracorporeal shock waves modulates viability and gene expression of human skeletal muscle cells: a controlled in vitro study

Stefan G. Mattyasovszky[1*†], Eva K. Langendorf[1†], Ulrike Ritz[1], Christoph Schmitz[3], Irene Schmidtmann[2], Tobias E. Nowak[1], Daniel Wagner[1], Alexander Hofmann[1], Pol M. Rommens[1] and Philipp Drees[1]

Abstract

Background: Recent clinical and animal studies have shown that extracorporeal shock wave therapy has a promoting influence on the healing process of musculoskeletal disorders. However, the underlying biological effects of extracorporeal shock wave therapy on human skeletal muscle cells have not yet been investigated.

Methods: In this study, we investigated human skeletal muscle cells after exposure to radial extracorporeal shock waves in a standardized in vitro setup. Cells were isolated from muscle specimens taken from adult patients undergoing spine surgery. Primary muscle cells were exposed once or twice to radial extracorporeal shock waves in vitro with different energy flux densities. Cell viability and gene expression of the paired box protein 7 (Pax7), neural cell adhesion molecule (NCAM), and myogenic factor 5 (Myf5) and MyoD as muscle cell markers were compared to non-treated muscle cells that served as controls.

Results: Isolated muscle cells were positive for the hallmark protein of satellite cells, Pax7, as well as for the muscle cell markers NCAM, MyoD, and Myf5. Exposure to radial extracorporeal shock waves at low energy flux densities enhanced cell viability, whereas higher energy flux densities had no further significant impact. Gene expression analyses of muscle specific genes (Pax7, NCAM, Myf5, and MyoD) demonstrated a significant increase after single exposure to the highest EFD (4 bar, 0.19 mJ/mm^2) and after double exposure with the medium EFDs (2 and 3 bar; 0.09 and 0.14 mJ/mm^2, respectively). Double exposure of the highest EFD, however, results in a significant down-regulation when compared to single exposure with this EFD.

Conclusions: This is the first study demonstrating that radial extracorporal shock wave therapy has the potential to modulate the biological function of human skeletal muscle cells. Based on our experimental findings, we hypothesize that radial extracorporal shock wave therapy could be a promising therapeutic modality to improve the healing process of sports-related structural muscle injuries.

Keywords: Shock wave therapy, Muscle injury, Primary muscle cells

* Correspondence: stefan.mattyasovszky@gmx.de
†Equal contributors
[1]Department of Orthopedics and Traumatology, University Medical Centre of the Johannes Gutenberg-University of Mainz, Langenbeckstraße 1, 55131 Mainz, Germany
Full list of author information is available at the end of the article

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The Effectiveness of Extracorporeal Shock Wave Therapy in Lower Limb Tendinopathy

CME

A Systematic Review

Sethu Mani-Babu,* MBBS, Dylan Morrissey,*† PhD, Charlotte Waugh,* PhD, Hazel Screen,‡ PhD, and Christian Barton,*§||¶ PhD
Investigation performed at Queen Mary University of London, London, UK

Background: There is accumulating evidence for the effectiveness of extracorporeal shock wave therapy (ESWT) when treating lower limb tendinopathies including greater trochanteric pain syndrome (GTPS), patellar tendinopathy (PT), and Achilles tendinopathy (AT).

Purpose: To evaluate the effectiveness of ESWT for lower limb tendinopathies.

Study Design: Systematic review and meta-analysis.

Methods: PubMed (Medline), Embase, Web of Knowledge, Cochrane, and CINAHL were searched from inception to February 2013 for studies of any design investigating the effectiveness of ESWT in GTPS, PT, and AT. Citation tracking was performed using PubMed and Google Scholar. Animal and non–English language studies were excluded. A quality assessment was performed by 2 independent reviewers, and effect size calculations were computed when sufficient data were provided.

Results: A total of 20 studies were identified, with 13 providing sufficient data to compute effect size calculations. The energy level, number of impulses, number of sessions, and use of a local anesthetic varied between studies. Additionally, current evidence is limited by low participant numbers and a number of methodological weaknesses including inadequate randomization. Moderate evidence indicates that ESWT is more effective than home training and corticosteroid injection in the short (<12 months) and long (>12 months) term for GTPS. Limited evidence indicates that ESWT is more effective than alternative nonoperative treatments including nonsteroidal anti-inflammatory drugs, physical therapy, and an exercise program and equal to patellar tenotomy surgery in the long term for PT. Moderate evidence indicates that ESWT is more effective than eccentric loading for insertional AT and equal to eccentric loading for midportion AT in the short term. Additionally, there is moderate evidence that combining ESWT and eccentric loading in midportion AT may produce superior outcomes to eccentric loading alone.

Conclusion: Extracorporeal shock wave therapy is an effective intervention and should be considered for GTPS, PT, and AT particularly when other nonoperative treatments have failed.

Keywords: extracorporeal shock wave therapy; greater trochanteric pain syndrome; patellar tendinopathy; Achilles tendinopathy

Tendinopathies are clinically characterized by localized, painful, and tender tendon thickening, which causes a loss of function.[27] Lower limb tendinopathies, including greater trochanteric pain syndrome[2,26] (GTPS; commonly due to gluteal tendinopathy),[3] patellar tendinopathy[15] (PT), and Achilles tendinopathy[16] (AT), are prevalent among both athletes and sedentary patients. Tendinopathies are often difficult to treat, leading to substantial impacts on health, sporting activity, physical activity for health, and occupation.[4,27]

There is no agreement on the best form of management, with extracorporeal shock wave therapy (ESWT) recently being proposed as a viable treatment option for lower limb tendinopathies with varying reports of effectiveness. Originally used for the treatment of kidney stones, ESWT is now being used for several orthopaedic conditions, with level 1a evidence recently established for the treatment of calcific rotator cuff tendinosis.[12] Despite this early indication of its potential benefit in treating tendinopathies, the true potential for pain reduction and improved function remains unclear.

Decision making about whether to use ESWT and the energy levels, number of treatment sessions, and number of impulses to choose is hindered by the diversity of published works. The benefits of using a local anesthetic are also disputed.[14,22] Considering the growing popularity of ESWT as an intervention for lower limb tendinopathies in a clinical setting, this review aimed to assess the short-term (<12 months) and long-term (>12 months) effectiveness of ESWT in treating GTPS, PT, and AT.

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Review

Biological mechanism of shockwave in bone

Jai-Hong Cheng [a, b], Ching-Jen Wang [a, c, *]

[a] Center for Shockwave Medicine and Tissue Engineering, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine, Kaohsiung, Taiwan
[b] Medical Research, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine, Kaohsiung, Taiwan
[c] Department of Orthopedic Surgery, Kaohsiung Chang Gung Memorial Hospital and Chang Gung University College of Medicine, Kaohsiung, Taiwan

HIGHLIGHTS

- ESWT is a novel method in musculoskeletal disorders and other disease.
- The biologied effects of ESWT may be through mechanotransduction.
- Applications of ESWT are increasing.
- ESWT promotes tissue regeneration, wound healing, angiogenesis, bone remodeling, and anti-inflammation.

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ABSTRACT

Shockwave is a rapid, short duration acoustic wave that carries energy and can propagate through tissue medium. This kind of physical force can be a mechanical stimulus that induces biological effects in living tissue. Extracorporeal shockwave therapy (ESWT) acts as a mechanical stimulus which promotes biological healing processes through a mechanotransduction. The biological effects of ESWT are reported such as tissue regeneration, wound healing, angiogenesis, bone remodeling, and anti-inflammation. Until now, however, little is known about the basic mechanism of action of this type of therapy. This article describes the molecular mechanism on the current status of ESWT with pre-clinical and clinical applications for treating disorders in bone.

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1. Introduction

Extracorporeal shockwave therapy (ESWT) has been used for musculoskeletal disorders over 30 years. Several studies had

* Corresponding author. Department of Orthopedic Surgery, Kaohsiung Chang Gung Memorial Hospital, 123 Tai-Pei Road, Niao Sung District, Kaohsiung 833, Taiwan.
E-mail address: w281211@adm.cgmh.org.tw (C.-J. Wang).

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Case Study

Radial extracorporeal shock wave therapy for heterotopic ossification

Byung-Ju Ryu, MD[1)], Kang-Wook Ha, MD[1)], Jin-Young Lee, MD[2)], Sung-Hwan Kim, MD[1)], Ho-Jun Kwak, MD[1)], Pyong-Hwa Seol, MD[1)*]

[1)] *Department of Physical Medicine and Rehabilitation, Sahmyook Medical Center: Mangu-ro, Dongdaemun-gu, Seoul 02500, Republic of Korea*
[2)] *Department of Physical Medicine and Rehabilitation, National Traffic Injury Rehabilitation Hospital, Republic of Korea*

Abstract. [Purpose] To report the effects of radial extracorporeal shock wave therapy (RSWT) on heterotopic ossification (HO). [Subjects and Methods] Two cases of neurogenic HO in the upper extremity were administered RSWT using the MASTER PLUS® MP 2000 (Storz, Tägerwilen, Switzerland) and ultrasonographic guidance. The RSWT protocol consisted of 3,000 pulses at a frequency of 12 Hz during each treatment. The intensity level ranged from 2–5 bars, and it was administered 5 times a week for 4 weeks, a total of 20 treatments. [Results] RSWT improved pain, range of motion, and hand function in 2 patients with neurogenic HO in the upper extremity. [Conclusion] Further studies are needed to support these results and to understand the mechanism and to devise the protocol of RSWT for neurogenic HO.
Keywords: Extracorporeal shock wave therapy (ESWT), Heterotopic ossification, Brain injury

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INTRODUCTION

Radial extracorporeal shock wave therapy (RSWT) generates pressure waves through the collision of solid bodies[1)]. It has been widely used to treat various musculoskeletal injuries[2, 3)]. There are a few recent reports regarding the effectiveness of extracorporeal shock wave therapy (ESWT) on neurogenic heterotopic ossification (HO) in the lower extremity, but to our knowledge, the use of ESWT or RSWT to treat neurogenic HO in the upper extremity has not been reported in the literature[4)].

We report 2 cases of RSWT used to treat neurogenic HO in the upper extremities. In both cases, improvements in pain, range of motion (ROM), muscle strength, and hand function were observed.

Each patient gave their written informed consent and agreed to participate in the treatment. This case report was approved by the Ethics Committee of the Sahmyook Medical Center.

CASE A

A 49-year-old man was admitted to our physical medicine and rehabilitation (PMR) department. A subarachnoid hemorrhage (SA) occurred 10 months prior to admission and neurogenic HO of the left shoulder and elbow was diagnosed 2 months before his admission. He had been taking disodium etidronate 800 mg per day (Fig. 1). In spite of the medication, he continued to complain of constant pain, limited ROM, muscle weakness, and impaired hand function. RSWT was administered to the inferior portion of the coracoid process of the left shoulder and the medial epicondyle (ME) of the left elbow using ultrasonographic (USG) guidance. The target points of RSWT were the HO area that could be seen with USG.

*Corresponding author. Pyong-Hwa Seol (E-mail: sultaeng@hanmail.net)

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Effect of Extracorporeal Shock Wave Therapy on Denervation Atrophy and Function Caused by Sciatic Nerve Injury

JUNG-HO LEE, MS[1)], SUNG-HYOUN CHO, MS[1)*]

[1)] *Department of Physical Therapy, Daegu University Graduate school of Physical Therapy, Daegu University: 15 Naeri-ri, Jinlyang, Gyeongsan-si, Kyeongsangbuk-do, Republic of Korea. TEL: +82 10-3060-1330*

Abstract. [Purpose] The present study examined the effects of treatment using extracorporeal shock wave therapy (ESWT) on the muscle weight and function of the hind limb in sciatic nerve injury. [Subjects] Forty rats with sciatic nerve crushing injury were randomly divided into two groups: an ESWT group (n=20), and a control group (n=20). [Methods] The ESWT group received extracorporeal shock wave treatment, and the control group did not receive any treatment after injury. Experimental animals were measured for muscle weight on an electronic scale and were tested for function on a sciatic functional index (SFI). [Results] All groups showed significant increases in the weights of the left soleus and gastrocnemius muscles, and decreases in the weights of the right soleus and gastrocnemius muscles ($p<0.05$). Comparison of SFI scores and muscle weights between the groups showed significant differences in SFI scores, and the right soleus and gastrocnemius muscles ($p<0.05$) [Conclusion] Exercise programs that use ESWT can be said to be effective at improving the function of the sciatic nerve and preventing the denervation atrophy.

Key words: ESWT, Sciatic nerve, Peripheral nerve

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INTRODUCTION

Neurological damage from external injury or trauma occurs more often in the peripheral nervous system than in the central nervous system. Neurological damage to the peripheral nervous system may result in severe physiological, morphological, cytological, or functional impairments, such as loss of motor function of the muscles that are controlled by the damaged neurons[1)].

Similarly, a decrease in protein synthesis may cause denervation atrophy[2)], and inhibition of sensory neurons may cause dysesthetic sensation[3)]. Damage to the sensory and motor neurons may lead to functional disorders[4)].

There are two major types of treatment for peripheral nerve damage: invasive and non-invasive. Methods of invasive treatment include injection and surgery, and non-invasive treatments include electrical stimulation, exercise, aquatic therapy, and medication[5, 6)].

Extracorporeal shock wave therapy (ESWT), a non-invasive treatment, relieves the pain of peripheral nerve damage and promotes local arterial remodeling and cellular regeneration. It is also known as an effective treatment for enhancing muscle strength and decreasing muscle tone. Murata et al. examined the pain-relieving effect of extracorporeal shock wave treatment, and reported that ESWT activates axonal regeneration, which stimulates reinnervation and promotes amelioration of desensitization[7)]. Bolt et al., in their study of the functional and morphological effects of shock wave treatment on palmar digital nerve damage, reported that pain relief caused by changes in peripheral pain perception exerted a positive effect on peripheral nerve regeneration[8)]. However, research into the effects of ESWT on muscular atrophy and function of sciatic nerve damage is currently inadequate. Therefore, we studied the effects of ESWT on the inhibition of neurological muscular atrophy and functional improvement following sciatic nerve damage.

SUBJECTS AND METHODS

Subjects

This study used 40 eight-week-old Sprague-Dawley male rats weighing between 250 g and 300 g. Sciatic nerve crushing injury was induced in all the animals, which were then randomly divided into two groups: an experimental group (n=20) that received extracorporeal shock wave treatment, and a control group (n=20) that did not receive any treatment.

The experimental group received the first treatment immediately after the nerve crushing damage and, starting on the next day, received three treatments per week for two weeks (total of six treatments). All surgical procedures and experimental protocols followed Daegu University's guidelines and were approved by the Institution of Animal Care

*To whom correspondence should be addressed.
E-mail: cory0831@naver.com

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REVIEW Open Access

Extracorporeal shockwave therapy in musculoskeletal disorders

Ching-Jen Wang

Abstract

The sources of shockwave generation include electrohydraulic, electromagnetic and piezoelectric principles. Electrohydraulic shockwaves are high-energy acoustic waves generated under water explosion with high voltage electrode. Shockwave in urology (lithotripsy) is primarily used to disintegrate urolithiasis, whereas shockwave in orthopedics (orthotripsy) is not used to disintegrate tissues, rather to induce tissue repair and regeneration. The application of extracorporeal shockwave therapy (ESWT) in musculoskeletal disorders has been around for more than a decade and is primarily used in the treatment of sports related over-use tendinopathies such as proximal plantar fasciitis of the heel, lateral epicondylitis of the elbow, calcific or non-calcific tendonitis of the shoulder and patellar tendinopathy etc. The success rate ranged from 65% to 91%, and the complications were low and negligible. ESWT is also utilized in the treatment of non-union of long bone fracture, avascular necrosis of femoral head, chronic diabetic and non-diabetic ulcers and ischemic heart disease. The vast majority of the published papers showed positive and beneficial effects. FDA (USA) first approved ESWT for the treatment of proximal plantar fasciitis in 2000 and lateral epicondylitis in 2002. ESWT is a novel non-invasive therapeutic modality without surgery or surgical risks, and the clinical application of ESWT steadily increases over the years. This article reviews the current status of ESWT in musculoskeletal disorders.

Keywords: Extracorporeal shockwave therapy, Musculoskeletal disorders

Extracorporeal shockwave therapy (ESWT) began with an incidental observation of osteoblastic response pattern during animal studies in the mid-1980 that generated an interest in the application of ESWT to musculoskeletal disorders. In the past 10 to 15 years, shockwave therapy had emerged as the leading choice in the treatment of many orthopedic disorders including proximal plantar fasciitis of the heel [1-6], lateral epicondylitis of the elbow [7-10], calcific tendinitis of the shoulder [11,12] and. non-union of long bone fracture [13-15]. More recently, the use of ESWT had expanded to the treatment of patellar tendinopathy (jumper's knee) and Achilles tendinopathy [16-19], and avascular necrosis of the femoral head [20-22]. ESWT has gained significant acceptance from Europe (Germany, Austria, Italy and others) to South America (Brazil, Columbia, Argentina and others), Asia (Korea, Malaysia, Taiwan and others) and North America (Canada and USA), and this had led to the change of European Society for Musculoskeletal Shockwave Therapy to International Society for Musculoskeletal Shockwave Therapy (ISMST) in 2000. In USA, FDA (Food and Drug Administration) first approved the specific shockwave device, OssaTron (High Medical Technology, Lengwil, Switzerland, now Sanuwave/Alpharetta, GA) for the treatment of proximal plantar fasciitis in 2000 and lateral epicondylitis of the elbow in 2003. FDA also approved Epos (Dornier Medical System, Kennesaw, GA) for the treatment of plantar fasciitis and Sonocur (Siemens Medical Systems, Iselin, NJ) for the treatment of lateral epicondylitis of the elbow in 2002, Orthospec (Medispec, Germantown, MD) and Orbasone (Orthometrix, White Plains, NY) for the treatment of plantar fasciitis in 2005. In the meantime, many off-label uses of ESWT were also studied including calcific tendinitis of the shoulder, patellar tendinopathy, Achilles tendinopathy, and non-union of long bone fracture, avascular necrosis of the femoral head and others. The vast majority of the published papers including randomized control trials and cohort studies showed

Correspondence: w281211@adm.cgmh.com.tw
Department of Orthopedic Surgery, Section of Sports Medicine, Chang Gung University College of Medicine, Kaohsiung Chang Gung Memorial Hospital, 123 Ta-Pei Road. Niao Sung District, Kaohsiung City 833, Taiwan

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Effect of Extracorporeal Shock Wave Therapy on Hamstring Tightness in Healthy Subjects: A Pilot Study

Yong Wook Kim[1*], Won Hyuk Chang[2*], Na Young Kim[1], Jun Beom Kwon[1], and Sang Chul Lee[1]

[1]Department of Rehabilitation Medicine and Research Institute, Yonsei University College of Medicine, Seoul;
[2]Department of Physical and Rehabilitation Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea.

Purpose: To assess the effect of extracorporeal shock wave therapy (ESWT) for healthy participants with hamstring tightness.
Materials and Methods: This study was performed at a university rehabilitation hospital. Twenty nine healthy adults with hamstring tightness were enrolled and randomly allocated into four groups (ESWT, stretching exercise, ESWT with stretching exercise, and control). The effects of individual treatments were compared by the finger-to-floor test and popliteal angle.
Results: The ESWT group, stretching exercise group and ESWT with stretching exercise group had decreased finger-to-floor distances and right popliteal angles immediately after intervention, compared with the control group ($p<0.05$). At 4 weeks after completion of the interventions, finger-to-floor distances and the right popliteal angle in only the ESWT with stretching exercise group showed a significant improvement, compared with the control group ($p=0.008$ and 0.023).
Conclusion: While ESWT and stretching both reduced hamstring tightness immediately after interventions, only ESWT with stretching exercise maintained the significantly improved relief of hamstring tightness significantly after 4 weeks.

Key Words: ESWT, stretching, hamstring tightness, spasticity

INTRODUCTION

A number of factors can limit a joint's range of motion, including tightness of soft-tissue structures such as muscle, tendon, ligament, and joint capsule. When connective tissue is not stretched, the collagen component gradually shortens. As a result, the periarticular collagen and the connective tissue of the muscle shorten. Furthermore, immobilization of a muscle in a shortened position also causes a decrease in the muscle length through a decrease in the number of sarcomeres in the muscle.[1] The tightness of hamstring muscles is one of the main factors hindering performance in daily and sporting activities.[2] Tightness of the hamstrings has been reported to be associated with the occurrence of back pain in adults.[3]

Recently, extracorporeal shock wave therapy (ESWT), which has proven effective in musculoskeletal injuries, has been also proposed for treatment of spastic muscles.[4-7] ESWT was introduced in the 1990's and now is used for the treatment of musculoskeletal conditions, such as calcific tendinopathies of the shoulder, lateral epicondylitis of the elbow, and plantar fasciitis.[4] A shock wave is a sonic pulse characterized by an initial rapid rise of a high peak pressure in less than 10 nanoseconds, followed by a low tensile amplitude, a short life cycle of approximately 10 microseconds.[5] The effects of shockwaves in tendon pathologies can be through a biological mechanism called mechanotransduction, by which the tissues exposed to shockwaves convert the mechanical stimulation of the shockwaves into biochemical signals through the release of growth factors involved in neoangiogenesis, tendon proliferation, and collagen synthesis.[6] However, the mechanisms by which ESWT affects spasticity remain unclear. Obviously, it is not

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Corresponding author: Dr. Sang Chul Lee, Department of Rehabilitation Medicine and Research Institute, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea.
Tel: 82-2-2228-3711, Fax: 82-2-363-2795, E-mail: bettertomo@yuhs.ac

*Yong Wook Kim and Won Hyuk Chang contributed equally to this work.
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The biological effects of extracorporeal shock wave therapy (eswt) on tendon tissue

Angela Notarnicola
Biagio Moretti

Department of Neuroscience and Organs of Sense, University of Study "Aldo Moro" of Bari, Orthopedics Units, General Hospital of Bari, Italy

Corresponding author:
Angela Notarnicola
Department of Neuroscience and Organs of Sense,
University of Study "Aldo Moro" of Bari, Orthopedics Units,
General Hospital of Bari, Italy
e-mail: angelanotarnicola@yahoo.it

Summary

There is currently great interest in the use of Extracorporeal Shock Wave Therapy (ESWT) and in clarifying the mechanisms of action in tendon pathologies. The success rate ranges from 60% to 80% in epicondylitis, plantar fasciitis, cuff tendinitis, trocanteritis, Achilles tendinitis or jumper's knee. In contrast to urological treatments (lithotripsy), where shockwaves are used to disintegrate renal stones, in musculoskeletal treatments (orthotripsy), shockwaves are not being used to disintegrate tissues, but rather to microscopically cause interstitial and extracellular biological responses and tissue regeneration. The researchers are interesting to investigate the biological effects which support the clinical successes. Some authors speculated that shockwaves relieve pain in insertional tendinopathy by hyper-stimulation analgesia. Many recent studies demonstrated the modulations of shockwave treatment including neovascularization, differentiation of mesenchymal stem cells and local release of angiogenetic factors. The experimental findings confirm that ESWT decrease the expression of high levels of inflammatory mediators (matrix metalloproteinases and interleukins). Therefore, ESWT produces a regenerative and tissue-repairing effect in musculoskeletal tissues, not merely a mechanical disintegrative effect as generally before assumed. Based on the encouraging results of clinical and experimental studies, the potential of ESWT appears to be emerging. The promising outcome after this non-invasive treatment option in tendinitis care justifies the indication of shockwave therapy. Further studies have to be performed in order or determine optimum treatment parameters and will bring about an improvement in accordance with evidence-based medicine. Finally, meta-analysis studies are necessary to demonstrate the efficacy and safety of ESWT in treating tendinopathies.

Key words: shock waves, tendon, tendinopathies, biological effects.

Introduction

A tendon is a tough band of fibrous connective tissue, that usually connects muscle to bone and is capable of withstanding tension (1). Microscopically, the main components of tendons are the cells (tenocytes) and the Extra Cellular Matrix (ECM) (collagen, elastin, and ground substance).
Due to overuse and trauma, tendons are subjected to tendinopathies. The "injury" generally results in inflammation and degeneration, or weakening, of the tendon, which may eventually lead to tendon rupture. It was believed, in the past, that tendons could not undergo to matrix turnover and that tenocytes were not capable of repair. However, it has been shown more recently that Matrix Metallo Proteinases (MMPs) have a very important role in the degradation and remodeling of the ECM during the healing process after a tendon injury. In response to repeated mechanical loading or injury, cytokines may be released by tenocytes and can induce the release of MMPs, causing degradation of the ECM and leading to recurring injury and chronic tendinopathies. A variety of other molecules are involved, on the contrary, in tendon repair and regeneration. There are five growth factors that have been shown to be significantly up-regulated and active during tendon healing: Insulin-like Growth Factor 1 (IGF-I), Platelet-Derived Growth Factor (PDGF), Vascular Endothelial Growth Factor (VEGF), basic Fibroblast Growth Factor (b-FGF), and Transforming Growth Factor beta (TGF-beta).

History and overview of shock waves therapy

Shockwaves are defined as pressure waves (or transient pressure oscillations), that propagate in three dimensions and typically induce a clear increase in pressure within few nanoseconds (4). There are very rapidly rising positive pressure impulses from 5 to 120 MPa in about 5 ns, followed by a decrease to negative pressure values of –20 MPa (5).
Extracorporeal Shock Wave Therapy (ESWT) was firstly applied in a patient in 1980 to disintegrate kidney stones (2). The possibility to disintegrate stones in urolithiasis by SW offered the transfer to pathological neo-calcifications in musculoskeletal disorders. Loew and Jurgowski first described calcific tendonitis of the rotator cuff in 1993 (3). The dissolution of calcium deposits documented by X-rays appears to increase therapeutic indications. At an early stage,

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IN VIVO BIOLOGICAL RESPONSE TO EXTRACORPOREAL SHOCKWAVE THERAPY IN HUMAN TENDINOPATHY

C.M. Waugh[1,2], D. Morrissey[1], E. Jones[3], G.P. Riley[3], H. Langberg[4] and H.R.C. Screen[2,*]

[1]Centre for Sports and Exercise Medicine, Queen Mary University of London, UK
[2]School of Engineering and Materials Science, Queen Mary University of London, UK
[3]School of Biological Sciences, University of East Anglia, Norwich, UK
[4]CopenRehab, University of Copenhagen, Copenhagen, Denmark

Abstract

Extracorporeal shock wave therapy (ESWT) is a non-invasive treatment for chronic tendinopathies, however little is known about the *in-vivo* biological mechanisms of ESWT. Using microdialysis, we examined the real-time biological response of healthy and pathological tendons to ESWT. A single session of ESWT was administered to the mid-portion of the Achilles tendon in thirteen healthy individuals (aged 25.7 ± 7.0 years) and patellar or Achilles tendon of six patients with tendinopathies (aged 39.0 ± 14.9 years). Dialysate samples from the surrounding peri-tendon were collected before and immediately after ESWT. Interleukins (IL)-1β, IL-2, IL-4, IL-6, IL-8, IL-10, IL-12p70, IL-17A, vascular endothelial growth factor and interferon-γ were quantified using a cytometric bead array while gelatinase activity (MMP-2 and -9) was examined using zymography. There were no statistical differences between the biological tissue response to ESWT in healthy and pathological tendons. IL-1β, IL-2, IL-6 and IL-8 were the cytokines predominantly detected in the tendon dialysate. IL-1β and IL-2 did not change significantly with ESWT. IL-6 and IL-8 concentrations were elevated immediately after ESWT and remained significantly elevated for four hours post-ESWT ($p < 0.001$). Pro-forms of MMP-2 and -9 also increased after ESWT ($p < 0.003$), whereas there were no significant changes in active MMP forms. In addition, the biological response to ESWT treatment could be differentiated between possible responders and non-responders based on a minimum 5-fold increase in any inflammatory marker or MMP from pre- to post-ESWT. Our findings provide novel evidence of the biological mechanisms underpinning ESWT in humans *in vivo*. They suggest that the mechanical stimulus provided by ESWT might aid tendon remodelling in tendinopathy by promoting the inflammatory and catabolic processes that are associated with removing damaged matrix constituents. The non-response of some individuals may help to explain why ESWT does not improve symptoms in all patients and provides a potential focus for future research.

Keywords: Microdialysis, interleukin, mid-portion tendinopathy, conservative treatment, matrix metalloproteinase, extracorporeal shock wave therapy.

*Address for correspondence:
Dr Hazel Screen, Reader in Biomedical Engineering
School of Engineering & Materials Science
Queen Mary, University of London
Mile End Road, London, E1 4NS, UK
Telephone Number: 020 7882 6167
E-mail: h.r.c.screen@qmul.ac.uk

Introduction

Tendons are highly organised, hierarchical structures that transmit muscular forces to the skeletal system for creating movement or for joint stability. For effective force transfer, tendons are required to be stiff, whilst some extensibility allows energy storage for efficient locomotion (Shepherd and Screen, 2013). Tendons must be able to withstand the forces generated through muscular loading. However, repetitive and/or excessive overloading of the tendon, such as that experienced with endurance running or poor biomechanics is considered to be the major aetiological factor in the development of tendinopathies (Huang *et al.*, 2004; Kader *et al.*, 2002). Tendinopathies are a common and painful problem affecting both athletes (Kvist, 1991) and sedentary individuals (Rolf and Movin, 1997) causing a loss of function. Pathological changes, such as collagen fibre and fibril disorganisation, neovascularisation, and an increase in tenocyte proliferation and non-collagenous matrix quantity all provide evidence of a failed healing response to accumulated tendon damage (Astrom and Rausing, 1995; Jozsa and Kannus, 1997).

There are a number of conservative treatment options which have been shown to improve the symptoms associated with tendinopathy, including physiotherapy, high-volume image-guided injections and eccentric loading (Coombes *et al.*, 2010; de Vos *et al.*, 2010; Sussmilch-Leitch *et al.*, 2012). Whilst some papers have questioned its efficacy (Costa *et al.*, 2005; Zwerver *et al.*, 2011), a recent systematic review demonstrated that extracorporeal shock wave therapy (ESWT) is also largely successful in providing an alternative conservative tendinopathy treatment (10/11 papers examining the efficacy of ESWT in Achilles tendinopathy, and 6/7 papers for the patellar tendon report a significant improvement in symptoms after treatment; Mani-Babu *et al.*, 2014). ESWT is a non-invasive treatment in which the kinetic energy of acoustic shockwaves is concentrated on the area of pain and pathology, therefore applying mechanical forces to the tissue. Shockwaves are pressure waves, characterised by a rapid rise in positive pressure and high peak pressure amplitude, followed by a fall in pressure below ambient, *i.e.* negative pressure. The waves augment tissue density as a result of the positive and negative phases of the propagating wave passing through it, and in doing so deliver direct mechanical perturbations to the tissue. In the low-pressure phase of a passing shockwave, ESWT also causes cavitation (Ogden *et al.*, 2001), characterised by the formation of gas bubbles. The implosion of the bubbles with the rise in pressure from the subsequent shock wave produces a secondary energy wave, which also provides a mechanical stimulus (Delius, 1994; Schmitz *et al.*, 2013).

Extracorporeal shockwave therapy for patellar tendinopathy: a review of the literature

M T van Leeuwen, J Zwerver, I van den Akker-Scheek

Center for Sports Medicine, University Center for Sport, Exercise and Health, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands

Correspondence to: J Zwerver, Center for Sports Medicine, UMC Groningen, P.O. Box 30.001, 9700 RB Groningen, The Netherlands; j.zwerver@sport.umcg.nl

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ABSTRACT

Background and purpose: Extracorporeal shockwave therapy (EWST) has become a popular treatment for patellar tendinopathy. The purpose of this review was to study the effectiveness of ESWT treatment for patellar tendinopathy; to draft guidelines for an effective treatment protocol of ESWT treatment; and to identify topics for further research.

Methods: A computerised search of the Medline and Embase databases was conducted on 1 August 2007, to identify studies dealing with the effectiveness of ESWT for patellar tendinopathy.

Results: Seven articles describing the effectiveness of ESWT on patellar tendinopathy, all published after 2000, were included. These studies included a total of 283 patients (298 tendons), 204 of whom (215 tendons) were assigned to ESWT treatment. The treatment results were positive but most studies had methodological deficiencies, small numbers and/or short follow-up periods. Method of application and shockwave generation, energy level, number and frequency of treatments, use of (local) anaesthesia and method of localisation were variable.

Conclusion: ESWT seems to be a safe and promising treatment for patellar tendinopathy with a positive effect on pain and function. Based on current knowledge it is impossible to recommend a specific treatment protocol. Further basic and clinical research into the working mechanism and effectiveness of ESWT for patellar tendinopathy are necessary.

Patellar tendinopathy, also called jumper's knee, is a chronic overuse injury of the patellar tendon causing pain at the inferior pole of the patella.[1] The prevalence is particularly high in athletes.[2 3] Among elite volleyball and basketball players a prevalence over 40% has been described.[4] Because of its chronicity and a lack of consensus about which treatment is the most adequate,[4 5] patellar tendinopathy has a major impact on the career of many athletes and for some it is the reason to end their career prematurely.[2 6 7]

The aetiology of patellar tendinopathy is not completely understood, but repetitive overload is thought to be an important factor.[8 9] Histopathological examinations of affected patellar tendons revealed the absence of inflammatory cells and no increased levels of prostaglandin.[8] Consequently, the former term tendinitis should be replaced by tendinosis, which reflects the underlying process of tendon degeneration and the failed healing response.[10] The term tendinopathy is now often used clinically.[10]

Based on the present literature it is not possible to decide what is the most appropriate and effective treatment for patellar tendinopathy.[11 12] The results of the many conservative treatments are not always consistent or evidence-based.[7 8 13–15] Eccentric training has been proposed as the best conservative treatment, but results are not convincing.[7] When conservative treatment fails, most patients proceed to surgical treatment,[11 12] which according to Bahr *et al* produces excellent or good results in at most 45% of patients.[4]

Since the early 1990s, extracorporeal shockwave therapy (ESWT) has been used for the treatment of several chronic tendinopathies.[16] This non-invasive and safe therapy originates from urology, where it is used to pulverise kidney stones (lithotripsy).[17] In some studies, ESWT has shown promising results in the treatment of rotator cuff tendinopathy, extensor tendinopathy of the elbow and chronic plantar fasciitis.[16–20] ESWT is nowadays used as a treatment for patellar tendinopathy as well. The underlying working mechanism of ESWT on tendinopathies is not completely understood, though. Both an analgesic effect and a stimulating effect on tissue regeneration have been suggested as possible working mechanisms.[20–22] There is no consensus about ESWT treatment protocols.[16] Controversy exists about method of application and shockwave generation (focused or radial), energy level to be used, number and frequency of treatments, use of (local) anaesthesia and method of localisation (see table 1).[16 20]

The main purpose of this review was to study the effectiveness of ESWT treatment for patellar tendinopathy. The ultimate goal is to draft guidelines for an effective treatment protocol and to identify topics for further research.

MATERIALS AND METHODS

Literature search

A computerised search of the Medline and Embase databases was conducted on 1 August 2007 (for search terms see fig 1). The search was limited to literature published in English or German. There was no limitation for publication year. Animal studies were excluded. Articles were defined to be relevant for this review if their subject was ESWT for patellar tendinopathy. Further, all reference lists were hand-searched for other relevant articles. The selected articles were reviewed by the authors and judged on their relevance and contribution to the subject of this study. All seven studies published about ESWT for patellar tendinopathy were included. All authors independently assessed the methodological quality of these seven studies using the Delphi criteria.[23] Keywords were: patellar tendinopathy, jumper's knee, shockwave therapy, treatment, review.

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