REVIEW

Review Over the Therapeutic Benefit of Extracorporeal Shockwave Therapy in Orthopaedic Patients

Gavril GHEORGHIEVICI[1,2], Adriana Sarah NICA[1,3], Brindusa MITOIU[1,3], Delia CLANTAU[1,3], Emil HARITINIAN[1,2], Razvan CISMASIU[1,2], Cristian Ioan STOICA[1,2]

Abstract

Shockwaves can be defined as transient pressure oscillations which propagate in three dimensions and offer an increased pressure in a very short period of time. Biological effects of shockwave therapy have been proven to stimulate the release of angiogenic growth factors, and contribute to the improvement of blood supply which leads to the repair of bone and soft tissue. The role of ESWT in the treatment of chronic calcifying tendinitis of the rotator cuff has been evaluated in many studies. ESWT has been gaining attention as an alternative option to surgical excision of calcification or when other conservative options have not proven efficient. The main purpose for using ESWT in heel spur is to increase the local blood supply by inducing neovascularisation. This action influences the inflammatory process and furthermore stimulates the local metabolism. Also, shockwaves have been proposed as a possible treatment in early phases of femoral head necrosis in adults. In case of patellar tendinopathy *in vitro* studies have shown biological effects, while clinical effects remain unclear. Data suggests that ESWT associated with other physical modalities achieve realiable clinical importance of pain reduction in lateral epycondylitis. However there is still a lack of standardisation and a consensus is needed regarding frequency and intensity.

Keywords: shockwave, rehabilitation, orthopaedics.

Rezumat

Undele de șoc pot fi definite drept oscilații de presiune tranzitorii ce se propagă tridimensional și oferă o presiune mărită într-o durată scurtă de timp. Principalele efecte biologice se referă la stimularea eliberării de factori angiogenici și influențarea influxului sanguin ce conduce la repararea țesutului osos și a țesuturilor moi periarticulare. Rolul ESWT în tratamentul proceselor de calcificare dezvoltate la nivelul umărului a fost evaluat în numeroase studii. ESWT poate reprezenta o alternativă terapeutică la soluțiile chirurgicale sau atunci când alte opțiuni de tip conservator nu s-au dovedit a fi eficiente. Principalul motiv pentru utilizarea ESWT în patologia plantară este acela de a crește aportul sanguin local prin inducerea neovascularizației. Această acțiune afectează procesul inflamator și stimulează în același timp metabolismul local. De asemenea, tratamentul ESWT a fost propus în fazele incipiente ale necrozei aseptice de cap femural. În cazul tendinitei patelare, studiile *in vitro* au demonstrat efecte biologice, în timp ce efectele clinice rămân neclare. Datele din literatură sugerează că asocierea ESWT cu alte modificări fizice prezintă un impact clinic semnificativ în cazul epicondilitei laterale. Cu toate acestea, există încă o lipsă de standardizare și este necesar un consens privind frecvența și intensitatea.

Cuvinte cheie: ESWT, recuperare medicală, patologie ortopedică.

[1] „Carol Davila" University of Medicine and Pharmacy, Bucharest, Romania
[2] „Foișor" Clinical Hospital of Orthopaedics, Bucharest, Romania
[3] National Institute of Rehabilitation, Physical Medicine and Balneology, Bucharest, Romania

Corresponding author:
Gavril Gheorghievici, „Foișor" Clinical Hospital of Orthopaedics, Bucharest, Romania.
E-mail: gavril.gheorghievici@gmail.com

BACKGROUND

Shockwaves can be defined as transient pressure oscillations which propagate in three dimensions and offer an increased pressure in a very short period of time, typically in a matter of a few nanoseconds[1,2]. Their main chracteristics are represented by positive (PØ) and negative (P-)peak pressure, rise time (Tr) and impulsed width (Tw). The principles of shockwave application refer to the propagation of waves through tissue such as water, gas or inside solid state bodies, pressure pulses acting directly or indirectly regardless of the generating source[3,4].

The first use of ESWT on the musculoskeletal system was made by Karpman et al. in an attempt to desintegrate the surrounding bone cement in patients scheduled for endoprosthesis replacement on the hip joint[5]. He was then followed by Valchanou et al. who applied shockwave therapy in pseudoarthrosis in the possibility of fragmenting the bone tissue[6]. It was further noticed an improvement in pain and functional levels from the application of ESWT for different chronic insertion enthesiopathies. Analgaesic effect of ESWT was believed to be caused by overstimulation of the treated area which resulted in a reduction of signal transmission to the central nervous system. Although there weren't significant prospective studies, the number of ESWT applications had an extensive grouth in the nineties decade, even surpassing the number of applications used in urology for lithotripsy[7-9].

The main categories of shockwaves refer to focused shockwave therapy which involves single pressure pulses focused on a specific target and are generated in water inside the device, and radial shockwaves which are produced by acceleration of a projectile with the use of compressed air[10,11]. From a physical point of view the typical form of the shockwave is characterised by a very short ascent until the maximum pressure results from asymmetric attenuation when traveling through tissue[12]. Also, the biological effects of shockwave therapy tend to stimulate the release of angiogenic growth factors, and contribute to the improvement of blood supply which leads to the repair of bone and soft tissue[2,13]. Molecular effects of shockwaves have been observed in experimental models, especially regarding the release of substance P and prostaglandin E2 which can be responsible for the biological actions of ESWT. An indirect effect is the induction of cavitation, which is expressed as the appearence of gas filled bubbles in the presence of a negative pressure gradient[14,15].

It has been observed that ESWT can lead to the development of histological changes in the applied area, the effects being partially dose dependent. Focal infiltration of the inflammation occurs at the skin level, and focal necrosis of the muscle fiber associated with inflammatory reaction has been observed,but with complete disappearence in time[16,17]. Also, osteoneogenesis has been observed depending on dose in case of high energy application, but with no effect in case of low energy application[18-20]. Due to those changes, induced by the physical and biological properties of shockwaves, the present review proposes the analysis of ESWT impact in different musculoskeletal disorders.

MATERIAL AND METHODS

A systematic review was conducted with the purpose of collecting potentially eligible publications, accessing the electronic databases available PubMed, Embase, and Cochrane library using the following terms: shock wave/shockwave, ESWT, plantar fasciitis, lateral epicondylitis, calcifying tendinitis, shoulder, avascular necrosis, tendinopathy, insertional. The searches were limited to articles in English. Additional studies were searched using the reference list of the chosen articles.

RESULTS AND DISCUSSIONS

The assessment of search results evidenced a significant amount of eligible studies, but also a variation in application methodology and number of sessions. The role of ESWT in treatment of chronic calcifying tendinitis of the rotator cuff has been evaluated in many studies[21-27]. Calcifying tendinitis is a frequent condition in orthopaedic and rehabilitation practice and represents a well documented cause for shoulder pain. It is characterised by the deposit of calcium hydroxyapatite crystals inside rotator cuff tendons[28,29]. ESWT has been gaining attention as an alternative option to surgical excision of calcification or when other conservative options have not proven efficient. Some studies have suggested the use of ESWT in athletes with refractory tenditinis as a preintervention therapy before arthroscopic surgery. Favorable results have also been observed for treatment of superior lateral brachial cutaneous nerve compression syndrome (SLBCN). Pan et al. observe an allevation of pain intesity and an improvement of shoulder joint function in patients with SLBCN compared to the control group which received homone injection[31]. Kluter et al. analyses the associated effect of ESWT with electromagnetic transduction therapy (EMTT)

for rotator cuff tendinopathy on 86 patients and express a clinically relevant decrease of pain and higher Constant Murley scores compared to control group at baseline and follow-up period[32].

Plantar heel pain represents one of the most frequently met disorders of the foot region, well documented in the literature, but without obtaining a uniform diagnosis, mostly because the background pathways are still unclear[33,34]. Today, the term ,,painful heel" is used by many authors, as well as ,,heel spur", although the condition is not always clearly evidenced by x rays. ,,Fasciitis plantaris" is a term that refers to an inflammatory status of the plantar fascia in the proximity of the calcaneal insertion[35,36]. Main symptoms include pain, associated with decreased range of motion. A number of conservative treatments have been outlined, including physical therapy with low energy laser, ultrasound and iontophoresis associated with pharmacological treatment or steroid injections, but without clear evidence of their efficacy[37-40].

The main purpose for using ESWT is to increase the local blood supply by inducing neovascularisation. This action affects the inflammatory process and furthermore stimulates the local metabolism. In a meta-analysis on 9 studies and 935 patients on the use of shockwave therapy in chronic plantar fasciitis, the authors observed that ESWT groups had higher improvement rates than placebo groups (OR 2.58, 95%, [CI] 1.97–3.39, p<.001)[41-43].

Another discussion regards the number of sessions that are needed for heel spur. Most protocols involve 4 to 5 sessions, but there are trials that evaluated the effect of a single session of ESWT in plantar fasciitis. Scheuer et al. performed an observational study on 284 patients (363 feet) that received ESWT and were required to complete a clinical questionnaire immediately after ESWT administration and after 19-77 weeks of follow-up. 76% of patients from the group that was treated with only 1 session expressed satisfying pain relief. Although the authors suggested that a single session of ESWT could offer similar outcomes as multiple sessions, further data is needed to establish the suitable number of treatment sessions as well as the adequate energy flux density that is required to increase the effectiveness of the treatment[44].

A systematic analysis by Roerdink et al. on the possible complications that can result from plantar application, reviewed 39 studies and 2697 heels and observed that no complications are to be expected until one year post treatment. However there isn't any reliable data on long term complications, therfore some precautions are recommended. Also, in some cases transient pain after application, swelling and throbbing sensation were reported[45].

Shockwaves have been proposed as a possible treatment in early phases of femoral head necrosis in adults. From a morphopathological point of view, osteonecrotic lessions usually have similar patterns. Most frequently, it involves an undelying circulatory disorder, which is associated with bone cell destruction due to insufficient oxygen supply and malnutrition. Until now, no gold standard has been developed and treatment options are still in debate[46-50].

Conservative approaches include only measures that are designed to reduce the symptomatology without interrupting the progress of the disease. Shockwaves are documented to stimulate bone regeneration, and it has been suggested that it may also induce specific signals for growth and maturation of the mesenchymal progenitors of the bone marrow. At the same time, shockwaves produce increased concentrations of free radicals[51-55]. A link has been detected between morphogenic proteins (BMP) and shockwave activity regarding bone regeneration. Literature data evidences that fact that ESWT can increase the expression of BMP in calus during fracture healing. However, precautions should be given, especially because in high doses it can create an imbalance in calcium homeostasis which can lead to tissue damage[56-57]. In some case reports Durst et al. express the development of humeral head osteonecrosis, 3 years after the administration of high energy ESWT for calcific tendinitis, while Liu et al report a case of humeral head osteonecrosis in 3 month after receiving ESWT. Although these are isolated cases, it has been suggested that a diminished diameter of the anterior humeral circumflex artery in these two cases could explain for the development of complications[58,59].

In a systematic review by Zhang et al, with a total of 17 articles including 6 RCT, 2 cohorts, 9 open label trials and 2 case reports, the authors observed an improvement in motor function and pain relief in case of ESWT use for osteonecrosis of the femoral head. Although the imagistics evidenced a reduction of bone marrow edema, the evolution of bone necrosis could not be stopped after ESWT. Also, the association of other conservative treatments with shockwave therapy did not influence the final effect[60]. However ESWT could offer some benefit in case of hip endoprosthesis decision, granting better bone conditions for the surgeon and a higher bone mass density.

Mackert et al. (2017) study the effect of low energy ESWT on metaphyseal fracture healing in osteoporotic rat models, and observe promising effects including an improvement of the biomechanical characteristics, enhanced callus quantity and quality and a modified expression of bone specific transcription factors[61]. This could prove beneficial, especially because osteoporotic fractures present a severely diminished bone quality, which often requires surgical fixation. Nontheless, diminished bone mass density contributes to prolonged healing periods and increases the risk of instability and complication rates. Therfore, ESWT could present as an alternative treatment option, with minimal side-effects compared to surgical or pharmacological modalities.

In case of epycondylitis humeri radialis or ,,tennis elbow", there are numerous conservative options that are proposed as main therapeutic option, surgical interventions being indicated only in a small number of refractory cases[62-65]. ESWT has been recommended as viable treatment option for these patients. However, a recent meta-analysis evidenced differences between the groups the received shockwave therapy and placebo group but not in a significant manner. On the other side, the group that received ESWT along with other physical modalities reached a reliable clinical significance of pain reduction[66-69].

ESWT role has been evaluated in sport pathologies such as patella syndrome and tibial anterior syndrome[70,71].

Patella syndrome or ,,jumper's knee" represents a typical insertion tendinopathy, frequently caused by repetitive jumps. The syndrome is characterised by microruptures at the tendon to bone junction and is associated with fibrinoid necroses and mucoid degeneration[72]. Van der Worp et al. (2012) perform a systematic review in order to identify randomized controlled trials that studied the effectiveness of ESWT for patellar tendinopathy. It was observed from the analysis that in vitro studies show biological effects, while clinical effects remain unclear[73]. The conflicting data is however determined by multiple reasons. The first reason is the absence of a gold standard for the diagnosis of a tendinopathy. Secondly, shockwaves are more effective in some stages of evolution compared to other stages, and lastly the effectiveness is influenced by the methodological aspects which include the number of pulses, intensity and focal depth. In a systematic review by Haake et al.[74] with the inclusion of 20 eligible studies, it was observed a variation of treatment sessions from 1 to 20 and also a disconcorcance of the number of impulses that varied from 500 to 2500. Tibial anterior syndrome is often triggered by sudden load peaks and intensive running and consists of pain localised in the middel and lower third of the tibialis anterior, representing the third most common sports injury after achillodynia and stress fracture[75]. By some authors, ESWT is proven more effective than traditional conservative treatments including nonsteroidal anti-inflammatory medication, standard physiotherapy program, kinetotherapy or, and the use of a knee strap[76].

Analysis of ESWT outcomes for painful stump neuroma has been documented in the literature. Jung et al. randomize thirty patients with stump neuroma at the distal end of an amputation site into two groups. One group benefited from ESWT at the area of the neuroma site which was identified using ultrasound guidance, and the second group benefited from transcutaneous electrical nerve stimulation and pharmacological treatment. Changes in McGill pain questionnaire were observed, but no significant changes in size or pressure threshold. However, the study demonstrated that the application of ESWT could reduce the side effects generated through injection therapies and surgical treatments[77].

Greater trochanteric pain syndrome (GTPS) represents a clinical condition which includes pain and tenderness around the greater trochanter area, which can radiate to the lateral side of the hip or thigh and is generally associated with trochanteric bursitis, but literature also suggests a degeneration process or a tearing of the gluteal tendons[78,79]. Conservative treatment consists of medication, rest, physical therapy or corticosteroid injections. Surgical treatment with the lengthening of iliotibial band and fascia is considered only in refractory cases[80]. Seo et al. investigate with the use of MRI the outcome of ESWT in GTPS patients and obtain succesuful rates of pain reduction over long term follow up[81].

Other studies have tried to evaluate effectiveness of acupuncture compared to ESWT, resulting in favorable data for both treatments regarding pain relief. Also, the authors found no significant improvement of DASH score and maximum grip strengh for both shockwave therapy and acupuncture. However the study had certain bias issues, including a relatively small sample of patients and also the fact that most enrolled patients reported to have applied massage therapy by themselves during the treatment period which could have lead to an underestimation of therapeutic effect in the stu-

died groups. The statement is correlated with a meta-analysis by Biset et al.[82] that reflected a positive effect of manipulative massage on lateral epicondylitis[83].

Other indications of ESWT have been linked to treatment of skin lessions, some authors finding an in vitro bactericidal effect. Due to the fact that surface defects were involved, modifications of the shockwave head had to be made, in order for it not to be focused but planar to the treated area. The authors used low energy flow densities, with no anesthesia being necessary due to defocusing and the low energy flux. Encouraging results were obtained, with none of the patients experiencing a worsening of the wound, and a lessening of the infection was observed after the first session[84]. Sho et al. perform a prospective study regarding effects of ESWT on burn patients with developed scar pain which included 40 patients with complete epithelization of open skin wounds that underwent skin grafting. Shockwave therapy was applied around the primary treatment site in accordance with the patients pain tolerarance with an energy flux density of 0.05 to 0.15 mJ/mm^2 and a number of 100 impulses-cm^2. Significant differences were reporded regarding pain threshold, and Roles and Maudlsley scores compared to sham group after 3 sessions, offering promising perspective over wound recovery[85].

Non orthopaedic indications refer to the benefit of using ESWT as a treatment option for ischemic cardiomyopathy. Different authors have studied in vitro and in vivo effects based on the fact that shockwaves can induce angiogenesis. Nishida et al.[86] apply ESWT on single donor human umbilical vein endothelial cells, and observe a significant up-regulation of the mRNA expression of vascular endothelial growth factor and its receptors in vitro. Also, an increase of the regional myocardial blood flow was detected, the results suggesting a possible non-invasive therapeutic strategy for ischemic heart disease. Vainer et al.[87] evaluate the feasibility of ESWT in 33 patients with end-stage coronary artery disease with the application of 9 sessions of shockwave with ECG and echocardiography guidance. The assessment of patients included nitrate use, myocardial scintigraphy, and MRI. The results evidenced at 4 month follow-up a reduction of angina symptoms and nitrate use and an increase in exercise tolerance. Favorable results were observed in the myocardial uptake within the stress myocardial scintigraphy.

CONCLUSIONS

Shockwave therapy can be indicated as an alternative treatment to surgical modalities or when other conservative methods have been proven insufficient. Further *in vitro* and placebo controlled studies are needed to establish the role of shockwaves in avascular necrosis of the femoral head. Low energy ESWT seems to bring a significant improvement in pain levels and shoulder function and can contribute to the resorbtion of calcium deposits. Action mechanisms of ESWT need additional research, but accepted biological effects include an ingrowth of neovascularization and a stimulation of angiogenetic growth factors.

There is potential of posponing or replacing surgical interventions in many orthopaedic disorders with the use of ESWT, but there is still a lack of standardisation and a consensus is needed regarding frequency and intensity.

Abbreviations

ESWT	Extracorporeal shockwave therapy
(PØ)	Positive peak pressure
(P-)	Negative peak pressure
(Tr)	Rise time
(Tw)	Impulse width
BMP	Binding morphogenic proteins
GTPS	Greater trochanteric pain syndrome
DASH	The Disabilities of the Arm, Shoulder and Hand Score
EMTT	Electromagnetic transduction therapy
SLBCN	Superior Lateral Brachial Cutaneous Nerve Compression Syndrome

Compliance with ethics requirements:

The authors declare no conflict of interest regarding this article.

The authors declare that all the procedures and experiments of this study respect the ethical standards in the Helsinki Declaration of 1975, as revised in 2008(5), as well as the national law. Informed consent was obtained from all the patients included in the study.

References

1. Gerdesmeyer L, Maier M,Haake M,Schmitz C. Physical-technical principles of extracorporeal shockwave therapy (ESWT) Orthopade. 2002 Jul;31(7):610-7.
2. M. Delius, K. Draenert, Y. Al Diek, Y. Draenert, Biological effects of shock waves: in vivo effect of high energy pulses on rabbit bone, Ultrasound Med. Biol. 21 (1995) 1219e1225.
3. Delius M: Lithotripsy. Ultrasound Med Biol 26 (Suppl 1):55-58, 2000
4. Hundt E. (1974) Die Physik, Bibliographisches Institut Mannheim-Dudenverlag, S.360
5. Karpmann RR, Magee FP, Gruen TWS, Mobley T: The plithotriptor and its potential use in the revision of total hip arthroplasty. Orto Rev 1987,26:38-42.Zitiert nach:Clin Orthop Relat Res. 2001 Jun;(387):4-7.The lithotriptor and its potential use in the revision of total hip arthroplasty.Karpman RR, Magee FP, Gruen TW, Mobley T.
6. Valchanou VD, Michailov P. High energy shockwaves in the treatment of delayed and nonunion of fractures. Int Orthop 1991.15:181-184
7. Wang CJ. Extracorporeal shockwave therapy in musculoskeletal disorders. J Orthop Surg Res. 2012;7:11. Published 2012 Mar 20. doi:10.1186/1749-799X-7-11
8. Gerdesmeyer L, Scott Weil L, Extracorporeal shockwave therapy clinical results, technologies, basics Data Trace Publishing Company 2007
9. Perez M, Weiner R, Gilley JC. Extracorporeal shock wave therapy for plantar fasciitis. Clin Podi Med Surg. 2003;20(2):323–34. doi: 10.1016/S0891-8422(03)00002-8.
10. Shockwave Therapy for Pain Associated with Upper Extremity Orthopedic Disorders: A Review of the Clinical and Cost-Effectiveness [Internet]. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2016 Sep. CADTH Rapid Response Reports.
11. Dion S, Wong JJ, Cote P, Yu H, Sutton D, Randhawa K, et al. Are passive physical modalities effective for the management of common soft tissue injuries of the elbow? A systematic review by the Ontario Protocol for Traffic Injury Management (OPTIMa) collaboration. Clin J Pain. 2016 Mar 28
12. Speed C. A systematic review of shockwave therapies in soft tissue conditions: focusing on the evidence. Br J Sports Med. 2014 Nov;48(21):1538–1542.
13. M. Delius, K. Draenert, Y. Al Diek, Y. DraenertBiological effects of shock waves: in vivo effect of high energy pulses on rabbit bone Ultrasound Med. Biol., 21 (1995), pp. 1219-1225
14. C.J. Wang, H.Y. Huang, H.H. Chen, C.H. Pai, K.D. YangEffect of shock wave therapy on acute fractures of the tibia: a study in a dog model Clin. Orthop. Relat. Res. (2001), pp. 112-118
15. G. Haupt, A. Haupt, A. Ekkernkamp, B. Gerety, M. ChvapilInfluence of shock waves on fracture healingUrology, 39 (1992), pp. 529-532
16. A. Ogden, A. Toth-Kischkat, R. SchultheissPrinciples of shock wave therapy Clin. Orthop. Relat. Res. (2001), pp. 8-17
17. Extracorporeal shock-wave therapy for musculoskeletal indications and soft tissue injuries [Internet]. Hartford (CT): AETNA; 2015. [cited 2016 Aug 24]. Available from: http://www.aetna.com/cpb/medical/data/600_699/0649.html.
18. P. Vavken, J. Holinka, J.D. Rompe, R. DorotkaFocused extracorporeal shock wave therapy in calcifying tendinitis of the shoulder: a meta-analysis Sports Health, 1 (2) (2009), pp. 137-144
19. Alves EM, Angrisani AT, Santiago MB. The use of extracorporeal shock waves in the treatment of osteonecrosis of the femoral head: a systematic review. Clin Rheumatol 2009;28:1247–51.
20. Haupt G. Use of extracorporeal shock waves in the treatment of pseudarthrosis, tendinopathy and other orthopedic diseases. J Urol. 1997;158(1):4–11.
21. L. Gerdesmeyer, S. Wagenpfeil, M. HaakeExtracorporeal shock wave therapy for the treatment of chronic calcifying tendonitis of the rotator cuff: a randomized controlled trial JAMA, 290 (2003), pp. 2573-2580
22. C.J. Hsu, D.Y. Wang, K.F. Tseng, Y.C. Fong, H.C. Hsu, Y.F. JimExtracorporeal shockwave therapy for calcifying tendinitis of the shoulder J. Shoulder Elb. Surg., 17 (1) (2008), pp. 55-59
23. Huisstede BM, Gebremariam L, van der Sande R, Hay EM, Koes BW. Evidence for effectiveness of Extracorporal Shock-Wave Therapy (ESWT) to treat calcific and non-calcific rotator cuff tendinosis – A systematic review. Man Ther. 2011;16:419–33
24. Louwerens JK, Veltman ES, van Noort A, van den Bekerom MP. The Effectiveness of high-energy extracorporeal shockwave therapy versus ultrasound-guided needling versus arthroscopic surgery in the management of chronic calcific rotator cuff tendinopathy: a systematic review. Arthroscopy. 2016 Jan;32(1):165–175.
25. Ioppolo F, Tattoli M, Di Sante L, Venditto T, Tognolo L, Delicata M, et al. Clinical improvement and resorption of calcifications in calcific tendinitis of the shoulder after shock wave therapy at 6 months' follow-up: a systematic review and meta-analysis. Arch Phys Med Rehabil. 2013 Sep;94(9):1699–1706.
26. Li W, Zhang SX, Yang Q, Li BL, Meng QG, Guo ZG. Effect of extracorporeal shock-wave therapy for treating patients with chronic rotator cuff tendonitis. Medicine (Baltimore). 2017; 96(35):e7940.
27. Notarnicola A, Moretti L, Maccagnano G, et al. Tendonitis of the rotator cuff treated with extracorporeal shock wave therapy: radiographic monitoring to identify prognostic factors for disintegration. J Biol Regul Homeost Agents 2016;30:1195–202.
28. Riley GP, Harrall RL, Constant CR. Cawston TE, Hazleman BL. Prevalence and possible pathological significance of calcium phosphate salt accumulation in tendon matrix degeneration. Ann Rheumatic Dis 1996; 55: 109–115
29. Malliaropoulos N, Thompson D, Meke M, et al. Individualised radial extracorporeal shock wave therapy (rESWT) for symptomatic calcific shoulder tendinopathy: a retrospective clinical study. BMC Musculoskelet Disord. 2017;18(1):513. Published 2017 Dec 6. doi:10.1186/s12891-017-1873-x
30. Chou WY, Wang CJ, Wu KT, Yang YJ, Cheng JH, Wang SW. Int J Surg. 2018 Mar;51:184-190. doi: 10.1016/j.ijsu.2018.01.036. Epub 2018 Feb 2.Comparative outcomes of extracorporeal shockwave therapy for shoulder tendinitis or partial tears of the rotator cuff in athletes and non-athletes: Retrospective study.
31. Pan ZX, Min XJ, Sun C, Du DK. Effectiveness of Extracorporeal Shockwave Therapy in Treating Superior Lateral Brachial Cutaneous Nerve Compression Syndrome Zhongguo Yi Xue Ke Xue Yuan Xue Bao. 2018 Jun 28;40(3):344-348. doi: 10.3881/j.issn.1000-503X.2018.03.008.
32. Klüter T1, Krath A, Stukenberg M, Gollwitzer H, Harrasser N, Knobloch K, Maffulli N, Hausdorf J, Gerdesmeyer L. Electromagnetic transduction therapy and shockwave therapy in 86 patients with rotator cuff tendinopathy: A prospective randomized controlled trial. Electromagn Biol Med. 2018;37(4):175-183.
33. Cutts S, Obi N, Pasapula C, Chan W. Plantar fasciitis. Ann R Coll Surg Engl. 2012;94(8):539-42.
34. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for plantar fasciitis: a matched case-control study. J Bone Joint Surg Am 2003; 85: 872–877
35. Ling Y, Wang S. Effects of platelet-rich plasma in the treatment of plantar fasciitis: A meta-analysis of randomized controlled trials. Medicine (Baltimore). 2018 Sep;97(37):e12110.
36. Lee TL, Marx BL. Noninvasive, Multimodality Approach to Treating Plantar Fasciitis: A Case Study. J Acupunct Meridian Stud. 2018 Aug;11(4):162-164.

37. McMillan AM, Landorf KB, Barrett JT, Menz HB, Bird AR. Diagnostic imaging for chronic plantar heel pain: a systematic review and meta-analysis. J Foot Ankle Res. 2009;2:32.
38. Donley BG, Moore T, Sferra J, Gozdanovic J, Smith R. The efficacy of oral nonsteroidal anti-inflammatory medication (NSAID) in the treatment of plantar fasciitis: a randomized, prospective, placebo-controlled study. Foot Ankle Int. 2007;28(1):20–23.
39. Osborne HR, Allison GT. Treatment of plantar fasciitis by LowDye taping and iontophoresis: short term results of a double blinded, randomised, placebo controlled clinical trial of dexamethasone and acetic acid. Br J Sports Med. 2006;40(6):545–549.
40. Hawke F, Burns J, Radford JA, du Toit V. Custom-made foot orthoses for the treatment of foot pain. Cochrane Database Syst Rev. 2008;(3):CD006801.
41. Sun J, Gao F, Wang Y, Sun W, Jiang B, Li Z. Extracorporeal shock wave therapy is effective in treating chronic plantar fasciitis: A meta-analysis of RCTs. Medicine (Baltimore). 2017; 96(15):e6621.
42. Grecco MV, Brech GC, Greve JM. One-year treatment follow-up of plantar fasciitis: radial shockwaves vs. conventional physiotherapy. Clinics (Sao Paulo). 2013;68(8):1089-95.
43. Buchbinder R, Ptasznik R, Gordon J, Buchanan J, Prabaharan V, Forbes A. Ultrasound-guided extracorporeal shockwave therapy for plantar fasciitis: a randomized controlled trial. JAMA. 2002;288(11):1364–72.
44. Scheuer R, Friedrich M, Hahne J, Holzapfel J, Machacek P, Ogon M, Pallamar M. Approaches to optimize focused extracorporeal shockwave therapy (ESWT) based on an observational study of 363 feet with recalcitrant plantar fasciitis. Int J Surg. 2016 Mar;27:1-7. doi: 10.1016/j.ijsu.2016.01.042. Epub 2016 Jan 20.
45. 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 Oct; 46:133-145
46. Malizos KN, Karantanas AH, Varitimidis SE, et al. Osteonecrosis of the femoral head: etiology, imaging and treatment. Eur J Radiol 2007;63:16–28.
47. Aldridge JR, Urbaniak JR. Avascular necrosis of the femoral head: etiology, pathophysiology, classification, and current treatment guidelines. Am J Orthop (Belle Mead, NJ) 2004;33:327–32.
48. Marker D. R., Seyler T. M., Ulrich S. D., Srivastava S., Mont M. A. Do modern techniques improve core decompression outcomes for hip osteonecrosis? Clinical Orthopaedics and Related Research. 2008;466(5):1093–1103. doi: 10.1007/s11999-008-0184-9.
49. Fan M., Peng J., Qin L., Lu S. Experimental animal models of osteonecrosis. Rheumatology International. 2011;31(8):983–994. doi: 10.1007/s00296-011-1819-9.
50. Gao Y.-S., Zhang C.-Q. Cytotherapy of osteonecrosis of the femoral head: a mini review. International Orthopaedics. 2010;34(6):779-782. doi: 10.1007/s00264-010-1009-5.
51. Alves EM, Angrisani AT, Santiago MB. The use of extracorporeal shock waves in the treatment of osteonecrosis of the femoral head: a systematic review. Clin Rheumatol 2009;28:1247–51.
52. Lin PC, Wang CJ, Yang KD, et al. Extracorporeal shockwave treatment of osteonecrosis of the femoral head in systemic lupus erythematosis. J Arthroplasty 2006;21:911–5.
53. Chen JM, Hsu SL, Wong T, et al. Functional outcomes of bilateral hip necrosis: total hip arthroplasty versus extracorporeal shockwave. Arch Orthop Trauma Surg 2009;129:837–41.
54. Algarni AD, Al Moallem HM. Clinical and Radiological Outcomes of Extracorporeal Shock Wave Therapy in Early-Stage Femoral Head Osteonecrosis. Adv Orthop. 2018;2018:7410246. Published 2018 Aug 19. doi:10.1155/2018/7410246
55. Johnson A. J., Mont M. A., Tsao A. K., Jones L. C. Treatment of femoral head osteonecrosis in the United States: 16-year analysis of the nationwide inpatient sample. Clinical Orthopaedics and Related Research. 2014;472(2):617–623. doi: 10.1007/s11999-013-3220-3.
56. Wang FS, Yang KD, Kuo YR, Wang CJ, Sheen-Chen SM, Huang HC, Chen YJ. Temporal and spatial expression of bone morphogenetic proteins in extracorporeal shock wave-promoted healing of segmental defect. Bone. 2003 Apr;32(4):387-96.
57. Wang CJ, Yang KD, Ko JY, Huang CC, Huang HY, Wang FS. The effects of shockwave on bone healing and systemic concentrations of nitric oxide (NO), TGF-beta1, VEGF and BMP-2 in long bone non-unions. Nitric Oxide. 2009 Jun;20(4):298-303. doi: 10.1016/j.niox.2009.02.006. Epub 2009 Mar 10.
58. Durst HB, Blatter G, Kuster MS. Osteonecrosis of the humeral head after extracorporeal shock-wave lithotripsy. J Bone Joint Surg Br 2002;84:744–6.
59. Liu HM, Chao CM, Hsieh JY, et al. Humeral head osteonecrosis after extracorporeal shock-wave treatment for rotator cuff tendinopathy. A case report. J Bone Joint Surg Am 2006;88:1353–6.
60. Zhang Q, Liu L, Sun W, Gao F, Cheng L, Li Z. Extracorporeal shockwave therapy in osteonecrosis of femoral head: A systematic review of now available clinical evidences. Medicine (Baltimore). 2017;96(4):e5897.
61. Mackert GA, Schulte M, Hirche C, et al. Low-energy extracorporeal shockwave therapy (ESWT) improves metaphyseal fracture healing in an osteoporotic rat model. PLoS One. 2017;12(12):e0189356. Published 2017 Dec 12. doi:10.1371/journal.pone.0189356
62. Vaquero-Picado A, Barco R, Antuña SA. Lateral epicondylitis of the elbow. EFORT Open Rev. 2016;1(11):391-397. Published 2016 Nov 22. doi:10.1302/2058-5241.1.000049
63. Antuña S, Barco R. Essentials in elbow surgery. A comprehensive approach to common elbow disorders. London: Springer Verlag, 2014.
64. Orchard J, Kountouris A. The management of tennis elbow. BMJ 2011;342:d2687–d2687. PMID: 21558359.
65. Nirschl RP, Ashman ES. Elbow tendinopathy: tennis elbow. Clin Sports Med. 2003;22(4):813–36. doi: 10.1016/S0278-5919(03)00051-6.
66. Smidt N, van der Windt DA, Assendelft WJ, Deville WL, Korthals-de Bos IB, Bouter LM. Corticosteroid injections, physiotherapy, or a wait-and-see policy for lateral epicondylitis: a randomised controlled trial. Lancet. 2002;359(9307):657–62. doi: 10.1016/S0140-6736(02)07811-X.
67. Barrington J, Hage WD. Lateral epicondylitis (tennis elbow): nonoperative, open, or arthroscopic treatment?Curr Opin Orthop.2003;14(4):291–5.
68. Weber C, Thai V, Neuheuser K, Groover K, Christ O. Efficacy of physical therapy for the treatment of lateral epicondylitis: a meta-analysis. BMC Musculoskelet Disord. 2015;16:223. Published 2015 Aug 25.
69. Taheri P, Emadi M, Poorghasemian J. Comparison the Effect of Extra Corporeal Shockwave Therapy with Low Dosage Versus High Dosage in Treatment of the Patients with Lateral Epicondylitis. Adv Biomed Res. 2017;6:61. Published 2017 May 29.
70. Peers, K.H. and Lysens, R.J. Patellar tendinopathy in athletes: current diagnostic and therapeutic recommendations. Sports Med. 2005; 35: 71–87
71. Schwartz A, Watson JN, Hutchinson MR. Patellar Tendinopathy. Sports Health. 2015;7(5):415-20.
72. Alfredson H, Ohberg L. Neovascularisation in chronic painful patellar tendinosis—promising results after sclerosing neovessels outside the tendon challenge the need for surgery. Knee Surg Sports Traumatol Arthrosc. 2005;13:74-80.
73. van der Worp H, van den Akker-Scheek I, van Schie H, Zwerver J. ESWT for tendinopathy: technology and clinical implications. Knee Surg Sports Traumatol Arthrosc. 2012;21(6):1451-8.

74. Haake M, Buch M, choellner C, Goebel F, Vogel M, Mueller I, Hausdorf J, Zamzow K, Schade-Brittinger C, Mueller HH. Extracorporeal Shockwave Therapy in the treatment of plantar fasciitis-Randomized multicenter trial. BMJ 2003, 327:75-77
75. Lohler H. (1995): Sports orthopaedics in atheletics- an analysis of the current situation. NSA (New Study in Athletics) 10 (4): 11-21
76. Wang CJ1, Ko JY, Chan YS,Weng LH,Hsu SL. Extracorporeal shockwave for chronic patellar tendinopathy. Am J Sports Med. 2007 Jun;35(6):972-8. Epub 2007 Feb 16.
77. Jung YJ, Park WY, Jeon JH, et al. Outcomes of ultrasound-guided extracorporeal shock wave therapy for painful stump neuroma. Ann Rehabil Med. 2014;38(4):523-33.
78. Barratt PA, Brookes N, Newson A. Conservative treatments for greater trochanteric pain syndrome: a systematic review. Br J Sports Med. 2017;51(2):97–104.
79. Chowdhury R, Naaseri S, Lee J, Rajeswaran G. Imaging and management of greater trochanteric pain syndrome. Postgrad Med J. 2014;90(1068):576–581.
80. Speers CJ, Bhogal GS. Greater trochanteric pain syndrome: a review of diagnosis and management in general practice. Br J Gen Pract. 2017;67(663):479-480.
81. Seo KH, Lee JY, Yoon K, et al. Long-term outcome of low-energy extracorporeal shockwave therapy on gluteal tendinopathy documented by magnetic resonance imaging. PLoS One. 2018;13(7):e0197460. Published 2018 Jul 17. doi:10.1371/journal.pone.0197460
82. Bisset L., Paungmali A., Vicenzino B., Beller E. A systematic review and meta-analysis of clinical trials on physical interventions for lateral epicondylalgia. Br J Sports Med. 2005;39:411–422.
83. Wong CW, Ng EY, Fung PW, Mok KM, Yung PS, Chan KM. Comparison of treatment effects on lateral epicondylitis between acupuncture and extracorporeal shockwave therapy. Asia Pac J Sports Med Arthrosc Rehabil Technol. 2016;7:21-26. Published 2016 Nov 24. doi:10.1016/j.asmart.2016.10.001
84. Schaden W, Thiele R, Kölpl C, et al. Extracorporeal shock wave therapy (ESWT) in skin lesions. 9th International Congress of the International Society for Musculoskeletal Shockwave Therapy (ISMST) News Letter ISMST. 2006;2:13–14.
85. Cho YS, Joo SY, Cui H, Cho SR, Yim H, Seo CH. Effect of extracorporeal shock wave therapy on scar pain in burn patients: A prospective, randomized, single-blind, placebo-controlled study. Medicine (Baltimore). 2016;95(32):e4575.
86. Nishida T, Shimokawa H, Oi K, Tatewaki H, Uwatoku T, Abe K, et al. Extracorporeal cardiac shock wave therapy markedly ameliorates ischemia-induced myocardial dysfunction in pigs in vivo. Circulation2004; 110:3055–3061.
87. Vainer J, Habets JH, Schalla S, et al. Cardiac shockwave therapy in patients with chronic refractory angina pectoris. Neth Heart J. 2016;24(5):343-9.