Extracorporeal Shock Wave Therapy in Orthopaedic Diseases

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Abstract

The application of extracorporeal shock wave therapy (ESWT) as a treatment for different orthopaedic conditions has experienced a rapid increase over the last several years. However the mechanism of action and the therapeutic effect is not clear. The aim of this study was to review the literature about the efficacy of ESWT in the treatment of plantar fasciitis, lateral epicondylitis, shoulder painful disorders and non-union fractures. Only randomized controlled studies published in the last 5 years were retrieved from electronic database and manual search. Results on efficacy of ESWT are controversial. Studies that have claimed therapeutic benefit did not fulfill scientific criteria and controlled randomized trials were not able to confirm significant improvement after treatment with ESWT.

KEY WORDS: ESWT, plantar fasciitis, lateral epicondylitis, shoulder disorders, non-union fracture.

Introduction

Originally used for the treatment of kidney stones ESWT has found its place in the treatment of variety of chronic orthopaedic conditions including plantar fasciitis, lateral epicondylitis (tennis elbow), calcific tendinitis of the shoulder, delayed union or non-union of fractures, osteonecrosis of the femoral head and other tendinopathies. Declared as a non invasive and safe treatment it has been applied as an alternative to surgical procedures especially in European clinics. Naturally generated shock waves can be observed in thunder and lightning, explosion and supersonic aircrafts. They can produce a dramatic increase in pressure amplitudes. Sometimes this pressure can break the windows and damage ear membranes. The energy released is usually expressed in joules (J) or milijoules (mJ) and pressure in kilopascals (kPa) and megapascals (MPa). Animal experiments performed 20 years ago revealed that shock waves had the potential to activate osteoblast cells and stimulate bone formation. Delayed and non-union fractures healed faster after being exposed to the shock waves (1). This and other research papers published in the eighties and early nineties introduced the new concept of orthopaedic "Extracorporeal Shock Wave Therapy'(ESWT)'. Before that shock waves were used mainly for kidney stone lithotripsy.

Shock Waves: Physical Principles

A shock wave can be defined as a sonic pulse with the following characteristics:

1. High Peak Pressure (50 MPa)
2. A short lifecycle (10 ms)
3. Fast pressure rise (less than 10 ns)
4. A broad frequency spectrum

In practice there are three methods applied in shock wave generation:

1. Electrohydraulic principle
2. Electromagnetic principle
3. Piezoelectric principle

All these techniques convert electrical to mechanical energy. They are called focused shock waves and their main characteristics are a very high peak pressure (10 – 100 MPa) and a very short rise time (less than 1 micro second) Recently another principle for generating pressure waves was implemented, so called a ballistic, radial or unfocused pressure wave (Figure 1). Ballistic pressure pulses are significantly lower in peak pressure (0,1-1 MPa), feature a longer rise time (more than 1000 micro seconds) and pulse duration. The effect of ballistic pressure pulses is strongest at the surface point of impact and that is why their therapeutic effect is limited to superficial targets. Depth of penetration is 3 to 3,5 cm. This type of ESWT has been used mainly in physiotherapy. The shock waves propagate through a homogeneous soft tissue with a speed of 1500 m/sec with negligible distortion. However, facing the tissue inhomogenities the shock wave will be modified by deviation from straight propagation, reflection, absorption etc. As a result a localized release of shock wave energy occurs. The direct effect of the energy released at interfaces of different tissue as well as the indirect effects of colliding cavitation bubbles is assumed to initiate the healing effects of shock wave therapy (2).

Molecular Biological Mechanisms of ESWT

Although ESWT has been used in orthopedic practice for many years, the molecular mechanism of its action is poorly understood. It has been postulated that mechanical energy converted from high frequency electricity, triggers the release of free radicals, vasodilatation and successive angiogenesis. Among the free radicals the role of nitrogen oxide (NO) was particularly investigated.

Properties of NO include:

- Vasodilatation by relaxation of smooth vascular musculature through cGMP stimulation.
- Macrophage activation to increase immune defense and cytotoxicity.
- Neurotransmitter

There are three isoenzymes of NO synthase (NOS) which using L-arginine as a substrate catalyses the synthesis of NO and citrulline. These are: endothelial NOS (eNOS), neuronal NOS (nNOS) and inducible NOS (iNOS). Experimental work on rats confirmed that calcium independent NOS activity was significantly increased after treatment with ESWT. Increase was observed 1. day and persisted for 28 days after ESWT. Calcium dependent NOS activity was evidently elevated 14 days after treatment (3). Immunohistological observation demonstrated that mesenchymal cells at fibrous tissue and chondral cells at hypertrophic cartilage displayed intensive iNOS expression. Chondral cells and osteoblasts at newly formed woven bone

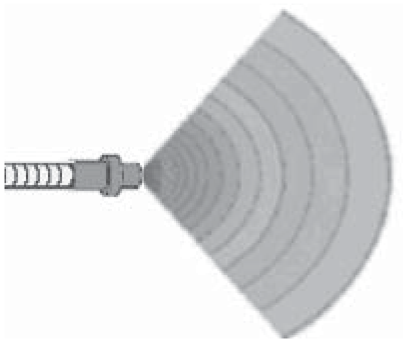

FIGURE 1. Ballistic (radial, unfocused ESWT)

junction appeared evident eNOS expression. Mature osteoblasts and osteoclasts at vascularized woven bone area showed strong nNOS immuno-reactivity. Based on these results one can conclude that NOS acts an important mediator to translate physical ESW treatment into biological reaction for mesenchymal cell proliferation and differentiation in the area of bone defect after exposure to ESW treatment. The eNOS is involved in new cartilage and bone formation. The nNOS is probably to mediate bone remodeling and angiogenesis (3). The role of mitogen activated protein kinase (MAPK), including extracorporal signal-regulated kinase (ERK) and p38 kinase (p38) on bone formation was also investigated. Animal model was used for experiment. Results suggest that ERK is active in the process of bone regeneration of segmental defect. The p38 is likely act important role in signaling cartilage formation in callus. ERK and p38 act as an important mediator to translocate biological signal into nuclei of cells to initialize mitogenic and osteogenic transcription of osteochondrogenic cells (4).

Analgesic Effect of ESWT

Experimental studies in vitro confirmed three major effects of ESWT. These are:

- Physical effects (mechanical pressure, cavitation)
- Chemical effects (diffusible radicals)
- Biologic effects (increase of membrane permeability) (5)(6)(7).

The relationship between these effects and pain relief is not clear. So far the mechanism of analgesia produced by ESWT is uncertain. Induction of neovascularization associated with mechanical and cavitation properties of shock waves are the most common proposed model (8). However gate control mechanism is also suggested (9). Decreased level of calcitonin gene-related peptide (CGRP) in dorsal root ganglia in rats was found after treatment with ESW. This could be related to pain relief (10). The possible role of spinal endogenous opioids (met-enkephalin and dynorphin) was also investigated. The level of these substances remains the same at 4 and 72 hours after exposure to ESWT. According to these results there is no proof that endogeneous opioids are responsible for analgesic effect of ESWT (11).

Clinical Studies on ESWT

Throughout the last 10 years there have been many publications about ESWT in orthopaedic treatment. Most of these publications were based more on clinical than on scientific background. While ESWT has been proved effective particularly for treatment of plantar fasciitis and tennis elbow, there have been very few randomized, prospective placebo controlled, double blinded studies performed. After reviewing the literature published in the last 5 years we selected only randomized control study articles. In a prospective randomized placebo-controlled double blind study an experimental group received ESWT of 1000 impulses of 0.08 mJ/mm for treatment of plantar fasciitis. 88% were pain free or had good results. None of placebo group was pain free, only 33.3% had good results. The treatment group showed significantly better outcome for morning and resting pain, pressure stamp-tolerance and walking ability. ESWT has been proved effective in treatment of plantar fasciitis (12). In another single blind randomized study on 60 patients with calcaneal enthesophytosis (calcaneal spur) it was found that the group treated with ESWT showed significant decrease of pain on the visual analog scale (VAS) and reduction of enthesophytosis larger than 1 mm on x-ray. Such improvement was not registered in placebo group (13).The effect of ESWT in patients with chronically painful proximal plantar fasciitis was compared with conventional conservative treatment including jontophoresis with Diclofenac and oral nonsteroidal anti-inflamatory drugs. Two years after treatment both groups showed pain decrease during activities of daily living. There was no statistically significant difference between groups (14). A randomized placebo - controlled, multiply blinded, crossover study conducted on patients with chronic plantar fasciitis concluded that the application of electrohydraulic high-energy shock waves to the heel is a safe and effective noninvasive method to treat chronic plantar fasciitis, lasting up to and beyond one year (15). Contrary to previous results, randomized, blinded multicentre trial study comprised 272 patients with chronic plantar fasciitis did not confirm better result with ESWT than with placebo. Authors concluded that ESWT is ineffective in treatment of chronic plantar fasciitis (16). After reviewing clinical trials on ESWT and plantar fasciitis Boddeker and co – authors found that many studies are incomplete and methodologically inadequate. After analysis of 21 relevant articles authors concluded that efficacy of ESWT can be neither confirmed nor excluded (17). Like plantar fasciitis results of treatment of lateral epicondylitis (tennis elbow) are also controversial. Perlick and co-authors evaluated the outcome of the ESWT and the operative treatment. They concluded that taking into account duration of symptoms, large scale of the primary treatment and operative hazards ESWT could be considered beneficial in the treatment of patients suffering from lateral epicondylitis (18). In a multicenter, blinded, randomized, placebo-controlled study 228 patients with chronic lateral epicondylitis were randomized to either active ESW treatment or to placebo group. Treated group received 1500 shocks directed at the affected site at a power of 18 kV. Authors concluded that ESWT was more effective than placebo in the treatment of chronic lateral epicondylitis, although both treatments might need to be performed to enhance the level of successful outcome (19). However, recently published papers were not able to confirm efficacy of ESWT in treatment of tennis elbow. Study performed on 60 patients randomly allocated to receive 1 session per week for 3 weeks of either sham or active ESWT revealed significant difference neither in pain reduction nor in quality of life between two groups (20). Review of the literature about ESWT and lateral epicondylitis was published in two articles. In the first one, a total of 20 studies were identified, 2 of which had been carried out as prospective, randomized and controlled studies. Regarding to clinical success, 40-80% of the patients achieved a good or very good result at follow up examinations after 3-12 months. However, in the single placebo-controlled and blinded study with the independent observer there was no difference between the ESWT group and the group treated with local anesthetic (21). In another study, 20 relevant articles were analyzed and it was concluded that at this point the efficacy of ESWT can be neither confirmed, nor excluded (22). The next common conditions treated with ESWT were shoulder painful disorders particularly calcifying tendonitis of the rotator cuff. In prospective study 115 patients diagnosed as tendinosis calcarea of the rotator cuff were treated with high energy ESWT once or twice. Subjectively 78% of group A (once treated) and 87% of group B (twice treated) judged the treatment to be successful. A radiographic examination 4 years after treatment revealed complete or partial resorption of the calcium deposit in 93% in both groups (23). In another study after comparing ESWT with radiation therapy authors concluded that ESWT appeared to be equivalent but not superior to radiotherapy (24) (25). A controlled, randomized study on the effects of low – energy shock wave therapy on the function and pain in tendonitis of the supraspinatus without calcification was performed. The patients receiving either ESWT or sham ESWT were examined 6 and 12 weeks after treatment by an independent observer. The statistical analysis showed no difference in results between the groups (26). The therapeutic effect of ESWT in shoulders with chronic calcific tendonitis was compared with transcutaneous electric nerve stimulation (TENS). Although the pain and calcium deposits were reduced significantly in both groups ESWT appeared to be more effective than TENS (27). Another double-blind, randomized, placebo-controlled trial to compare effect of high-energy, low energy (ESWT) or placebo on patients with chronic calcifying tendonitis of the rotator cuff was conducted. The result showed that both high energy and lower energy ESWT were significantly more efficient than placebo. Furthermore, high-energy ESWT appeared to be superior to low energy ESWT (28). Treatment of fracture non-union was another interesting field for ESWT. Birnbaum and co authors reviewed 52 papers referring to ESWT of the locomotor system. Conclusions regarding to possible applications in therapy were taken only from high quality publications of types A and B according to internationally accepted system of the American Association that treat the spinal problems. Most of the investigations showed a consolidation of the non union during a period of 3 months following ESWT. However long term results are not available (29). ESWT is usually considered as a safe therapeutic procedure with mild and temporary side effects. However particular studies on the side effects of ESWT are very rare. One of them compared side effects of ESWT with placebo in patients with lateral epicondylitis. A total of 272 patients from 15 centers were allocated at random to active ESWT or placebo ESWT. More side effects were recorded in the ESWT group than in placebo group. Most frequently were reddening of the skin (21,1%), pain (4,8 %) and small haematomas (3,0%). Migraine was registered in 4 and syncopes in 3 patients after receiving ESWT (30).

Conclusion

For the past 10 years ESWT has been intensively used in orthopaedic practice. At the moment three machines have been FDA approved for the use on humans, two for plantar fasciitis and one for lateral epicondylitis (tennis elbow). Almost all study emphasized high safety of this therapy with minimal side effects. However, results on efficacy of ESWT are still controversial. Many studies that claimed ESWT was efficient in treatment of musculoskeletal conditions did not fulfill scientific criteria. On the other side, most of the well established controlled studies which included double blind or single blind trials were not able to produce such results. There are multitude reasons to consider ESWT experimental and investigational rather than well documented therapeutic modality. The mechanism of action is speculative, difficult to quantify and prove. Treatment parameters have not yet been standardized and optimal dosages and frequency has not yet been established. There is still no consensus on when to differentiate between low and high-energy applications. There are no studies to compare the effect of focused versus ballistic (radial, not focused) techniques. One of the biggest advantages of ESWT in comparison to surgery was lower cost and faster healing of the treated tissue. However the surgery for plantar fasciitis, lateral epicondylitis and supraspinatus tendonitis with and without calcification are not very often and there are no enough studies to compare efficacy of ESWT and the surgical treatment on pain relief and functional outcomes. An opinion prevails that ESWT should be used only if other ordinary conservative treatments failed. Taking into account that in many patients, spontaneous resolution of pain and calcification is possible, the abuse of ESWT in the clinical practice should be considered as a serious problem. More studies need to be done for better understanding of the mechanism of action, to define optimal parameters and to create a specific clinical protocol for different musculoskeletal conditions.

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