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REVIEW ARTICLE

Extracorporeal shock wave treatment for shoulder calcific tendonitis: a systematic review

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Abstract The treatment of patients with calcific tendonitis is typically conservative, including physical therapy, iontophoresis, deep friction, local or systemic application of noninflammatory drugs, needle irrigation–aspiration of calcium deposit, and subacromial bursal steroid injection. If the pain becomes chronic or intermittent after several months of conservative treatment, arthroscopic and open procedures are available to curette the calcium deposit, and additional subacromial decompression can be performed if necessary. As an alternative, minimally invasive extracorporeal shock wave therapy (ESWT) has been postulated to be an effective treatment option for treating calcific tendinitis of the shoulder, before surgery. Herein we discuss the indications, mechanism of therapeutic effect, efficacy of treatment, and complications after ESWT application.

Keywords Calcific tendonitis · Shoulder · Extracorporeal shock wave treatment

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Introduction

Calcific tendinitis of the rotator cuff is a common enthesopathy of the shoulder, and is characterized by inflammation around calcium hydroxyapatite crystal deposits, usually located in the supraspinatus tendon, near its insertion place. Other affected sites include the infraspinatus, the teres minor, and the subscapularis tendon, in descending order of frequency [1]. The progress of this disorder passes through four phases in the following order: cell-mediated calcification/formative stage, resting stage, resorptive stage/deposit phagocytosis, and it ends with complete restitution of the tendon [2]. The disease mainly affects individuals between 30 and 50 years of age, is painful in 50% of patients, and frequently leads to considerable restriction of motion [3, 4]. It is believed that the disease only becomes acutely painful when the calcium deposit is undergoing resorption [5]. Most patients complain of impingement symptoms, including interrupted sleep and pain when working with the arm of the diseased shoulder abducted. Although the disease is in some cases self-limiting without specific therapy, spontaneous disappearance of periarticular calcifications was reported in 9.3% after 3 years and 27% after 10 years, but chronic pain over time is possible, causing morbidity [3, 6, 7]. The treatment of patients with calcific tendonitis is typically conservative (Table 1).

The reported success rates vary between 30 and 85% [9].

If the pain becomes chronic or intermittent after several months of conservative treatment, arthroscopic and open procedures are available to curette the calcium deposit, and additional subacromial decompression can be performed if necessary [10, 11].

Table 1 Conservative treatment options for calcific shoulder tendinitis [5, 8]

Treatment options
Non inflammatory drugs
Needle irrigation–aspiration of calcium deposit
Subacromial bursal steroid injection
Physical therapy
Iontophoresis
Deep friction

As an alternative, minimally invasive extracorporeal shock wave therapy (ESWT) has been postulated to be an effective treatment option for treating calcific tendinitis of the shoulder, before surgery [12, 13]. ESWT has long been used successfully in lithotripsy for the destruction of renal calculi and has been tested in the treatment of salivary gland calculi [14]. In the last few years ESWT has also been used for treatment of the non-union of long-bone fractures, plantar fasciitis, lateral epicondylitis of the elbow, chronic heel pain, and calcific tendinitis of the shoulder [15–19]. The treatment is based on the use of shock waves and pressure impulses capable of producing fragmentation of calcific deposits and reduction of painful symptomatology.

Technical features

Portable shock wave equipment and its application are pictured in Figs. 1, 2.

Fig. 1 Portable shock wave device (Sonocur Plus; Siemens, Munich, Germany)

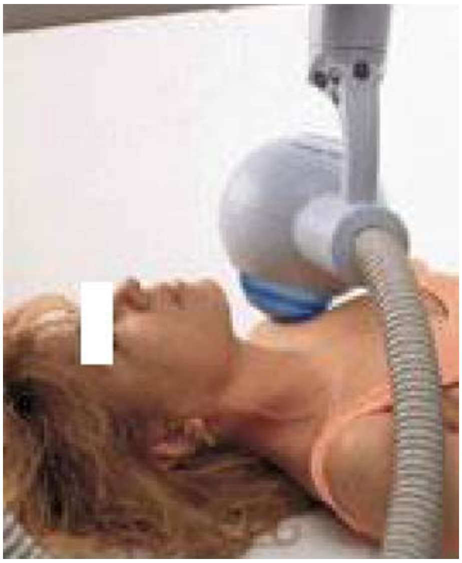

Fig. 2 Application of extracorporeal shock wave therapy (ESWT) on a painful shoulder

Today, three types of shock wave generators are used in daily medical practice: the electrohydraulic, the electromagnetic, and the piezoelectric generators [20].

Electrohydraulic generator

In the electrohydraulic generator, high voltage is applied to the tips of an electrode placed at the first focal point of an elliptical surface. An electrical spark is then generated and a shock wave is released because of vaporization of the water between the tips of the electrode and transmitted to the second focal point, which is the painful area of the body.

Electromagnetic generator

The electromagnetic generator uses an electromagnetic coil and a metal membrane opposite it. A high current pulse is released through the coil generating a strong varying magnetic field, which induces a high current in the opposite membrane. The electromagnetic forces cause rapid motion of the metal membrane away from the coil, creating a slow and low pressure acoustical pulse.

Piezoelectric generator

In the piezoelectric generator, a high voltage pulse passing through piezoelectric crystals of the spherical surface causes rapid contraction and expansion of the crystals, resulting in a pressure pulse and subsequent shock wave.

General features of energy applied

As an acoustic pressure disturbance created by the translation of energy via these generators, the wave is transmitted to the patient through either water or gel. Generally, a shock wave can be described as a single pulse with a wide frequency range (up to 20 MHz), high-pressure amplitude (up to 120 MPa), a low tensile wave (up to 10 MPa), a small pulse width at −6 dB and a rapid rise in pressure to 90% of the maximum pressure within 10 ns [21].

Extracorporeal shock wave therapy can be classified according to its energy levels. low energy shock waves have a focal energy flux density (EFD) of up to 0.08 mJ/mm^2, moderate-energy shock waves an EFD between 0.09 and 0.28 mJ/mm^2 and high energy shock waves up to 0.6 mJ/mm^2 [22].

Although lower-energy flux application is generally tolerated, with mild to moderate discomfort, high energy flux applications require local or regional anesthesia [23].

Indications for ESWT treatment

High energy shock wave therapy should be considered before surgery in patients with chronic calcific tendinitis after a minimum of 6 months of unsuccessful conservative treatment or clinical signs of subacromial impingement [24].

On standardized AP radiographs (Figs. 3, 4), the morphologic features of the calcareous deposit have to be homogenous in appearance and have well-defined borders (corresponding to Type I in the Gartner classification), or inhomogeneous in structure with a sharp outline, or homogenous in structure with no defined border (corresponding to Type II in the Gartner classification), because type III is frequently associated with a high percentage of spontaneous remission.

Fig. 3 X-ray showing calcific tendinitis before ESWT

Fig. 4 X-ray showing complete resorption of the calcium deposits 1 month after ESWT

Based on the theory of Loew et al. concerning the size of a mechanically impeding calcific depot in the subacromial space, it is suggested that a verified deposit with a diameter of 10 mm or more should be evident before ESWT is contemplated [25].

Mechanism of the therapeutic effect

The mechanisms of the therapeutic effect of ESWT for the treatment of calcifying tendinopathy are uncertain (Fig. 5).

Loew et al. proposed that increasing pressure within the therapeutic focus caused fragmentation and cavitation effects inside the amorphic calcifications and led to disorganization and disintegration of the deposits. A breakthrough of the calcific masses into the adjacent subacromial bursa or local resorptive reaction of the surrounding tissue induced by extracorporeal shock waves possibly led to the disappearance of the deposits. This mechanical irritation can effectively activate an inflamma-

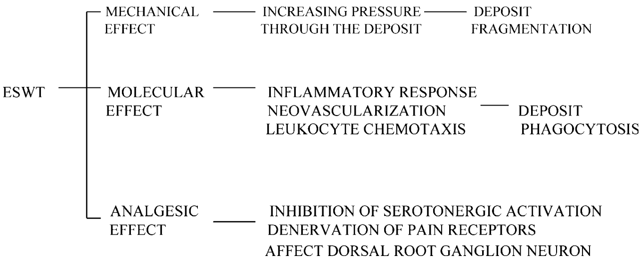

Fig. 5 Mechanisms of the therapeutic effect of ESWT

tory response on a microvascular level, with leukocyte recruitment, extravasation, chemotaxis, and phagocytosis [25].

Wang et al. hypothesized that calcium deposits are eliminated through a molecular mechanism of absorption associated with enhanced neovascularization and improved circulation at the tendon–bone junction after shock wave therapy, caused tissue healing [26]. In a report of 22 patients with femoral head necrosis, Ludwig et al. reported pain relief and improved Harris hip score 1 year after shock wave therapy and they believed that the success was due to improved circulation after shock wave therapy [27].

In a recent preclinical study in a rat model, shock waves induced neovascularization at the tendon–bone junction and this was confirmed by post-treatment histologic examination and angiogenesis-related markers. This effect appeared to increase over 8 weeks and persist over 12 weeks after shock wave administration [28].

Although some authors favor the theory of a direct mechanical disintegrating effect on the deposit, others prefer long-lasting hyperstimulation analgesia [29–31]. Haake et al. do not support the disintegrating theory because there was no significant difference found in the resorption rate between the group that received extracorporeal shock waves exactly focused on the deposit and the group that received extracorporeal shock waves focused on tuberculum majus [32]. Besides, Perlick et al. hypothesized that resorption of the calcific deposits is normally induced by a cellular mechanism and not through direct physical disintegration, because of the period of time before changes in the radiographs became evident [33].

Discrepancies in the impedance to surrounding soft tissue allow the energy transfer of shock waves [34]. For example, if the calcific deposits have a high degree of crystallized hydroxyapatite, making them fairly solid, then the resulting significant differences in impedance to surrounding soft tissue and the energy transfer can disintegrate the deposit. Whenever the surrounding soft tissue and the calcific deposits have similar densities, which happens when the calcific deposit is relatively liquid, the energy transfer may not be sufficient to cause adequate mechanical disintegration of the deposit. This phenomenon may be the reason for the clinically observed nonresponders, despite a theoretically ample energy level.

The fact that positive clinical results are not inevitably combined with a radiographically evident resorption of the calcific deposit underlines the fact that shock waves are well able to induce analgesia. This has previously been described by Daecke et al., who reported a significant number of patients initially benefitting from shock wave treatment despite no evident change in the deposits, but again suffering from their original symptoms 6 months later [12].

The theory of hyperstimulation analgesia involves stimulation of a brain stem feedback loop involving serotonergic activation via the dorsal horn, which exerts a descending inhibitory control of pain signal transmission [35]. Clinical pain relief after shock wave application may be caused by reduced calcitonin gene-related protein expression in the dorsal root ganglion neurons [36]. Furthermore, it has been suggested that ESWT causes inhibition or denervation of pain receptors [37].

Efficacy of the ESWT method

Numerous studies have evaluated the efficacy of ESWT as a method of managing calcific tendinitis. As a new method of treating calcifying tendinopathy it was first described by Dahmen et al., as a case report of six patients in 1992 [30].

Reported results in the literature support the therapeutic benefit and wide safety margin of ESWT for managing chronic tendinopathies of the rotator cuff. Recently, ESWT has shown encouraging preliminary results in the treatment of calcific deposits [25, 29]. Clinical success has been reported in 60–80% of patients from uncontrolled prospective trials [31, 38, 39]. Radiologic disintegration rates of the calcific deposit after ESWT vary from 47 to 77% [29, 40].

Cosentino et al., in a controlled single blind and randomized study, examined 35 patients who were undergoing regular treatment with ESWT and 35 patients a simulated treatment [41]. Each treatment consisted of 1,200 shocks with a frequency of 120 shocks a minute. The energy density used was 0.28 mJ/mm^2 for the first group and 0 mJ/mm^2 for the second group. In first group, ESWT effectively reduced painful symptomatology and increased the shoulder function ($p<0.001$). In 40% of cases partial resorption, and in 31% of cases complete resorption, of the calcium deposit was seen on plain X-rays ($p<0.001$). A mean increase in Constant-Murley score of 69% was observed, 6 months after treatment, but no improvement was noted in the placebo group ($p<0.001$).

It is known that the efficacy of the ESWT method depends on the amount of total energy applied, the frequency of shock wave delivered per second, and the guidance method.

Effects of different total energy applied

Many studies have demonstrated that clinical outcome after treatment with ESWT depends on the amount of total energy applied, the number of sessions of treatment, the radiologic/morphologic features of the deposit, and the rate of disintegration.

The amount of energy delivered influences clinical outcome and deposit elimination. Better clinical results, including pain relief and deposit resorption, are associated with high energy level application. Peters et al., in a prospective controlled, double-masked and randomized study, investigated clinical outcome and radiological resolution of calcium deposits, efficacy of different energy levels of ESWT in calcific tendinitis of the shoulder [42]. In their study, 90 patients with persistent pain over 6 months received one of two energy levels, 0.15 mJ/mm^2, 0.44 mJ/mm^2, or a sham energy level. The size of calcium deposits ranged from 1 to 3 cm in diameter. Treatment was given at 6-weekly intervals until symptoms resolved. Patients who received the low energy level experienced less pain during treatment, but about four times more applications than those with the high energy level, until the symptoms resolved ($p<$ 0.001). At the 6-month follow-up the patients treated with the low energy level had residual calcification and recurrence of pain (87%), but the patients treated with the high energy level had no residual calcification or recurrence of pain. Although 3 individuals (8%), after sham treatment, experienced intermittent slight alleviation of pain, it was not to a degree that allowed reduction or elimination of anti-inflammatory medication, and 26 of them (92%) had no relief at all. Besides, none of the patients receiving sham treatment presented transformation or complete resolution of calcium deposits.

Similarly, Perlick et al. in a single blind and randomized study, investigated the effects of various extracorporeal shock wave energy levels and impulse rates in 80 patients with persistent symptoms over 12 months [33]. Two groups of 40 patients each received 2,000 impulses twice, with an energy flux density of 0.23 mJ/mm^2 (group 1) and the other 0.42 mJ/mm^2 (group 2) in two sessions with an interval of 3 weeks between treatments. Radiographs obtained 1 year after shock wave treatment revealed complete resorption in 6 patients (15.0%) in group 1 and 14 patients (35.0%) in group 2. Partial resorption was observed in 9 patients (22.5%) in group 1 and 8 patients (20.0%) in group 2. After 1 year the Constant and Murley score increased from 46 to 68 at 0.23 mJ/mm^2 and from 48 to 73 at 0.42 mJ/mm^2, with no statistical difference between the two groups ($p>0.05$). Also, range of motion showed an increase from 18.2 to 26.8 in group 1 (0.23 mJ/mm^2) and from 19.5 to 29.3 in group 2 (0.42 mJ/mm^2; $p>0.05$) after 12 months.

Furthermore, it has been purported that a low energy level may have little or no effect in patients' symptoms or resorption of calcific deposits. Schmitt et al. in a controlled, single blind and randomized study, evaluated the effects of low energy shock wave therapy by comparing 20 patients treated with an energy flux density of 0.11 mJ/mm^2 with a control group who underwent sham ESWT after local anesthesia [19]. They found no difference in the Constant and Murley score or pain and therefore did not recommend low energy ESWT for therapy. This is comparable to the clinical results of Buch et al., who found either partial or total resorption of calcium deposits in only 13% after low energy ESWT and in 66% after high energy ESWT at the 6-week follow-up [43].

Effects of different frequency of shock wave delivered

The frequency of shock waves delivered per second in ESWT probably affects clinical outcome. In a prospective, randomized trial, Daecke et al. compared two applications versus one application of 2,000 shock wave impulses with an energy flux density of 0.3 mJ/mm^2, with an interval of 1 week, in 115 patients [44]. Calcific deposits were diminished statistically significantly in patients who received two sessions of treatment ($p=0.46$). As a matter of fact, complete elimination of the deposit was seen in 54% of patients (two sessions) and in 33% of patients (one session), and partial disintegration was seen in 23% of patients (one session) and 14% of patients (two sessions) on X-rays. Although 54% of patients treated in two sessions versus 45% of patients treated in one session presented with no pain after 6 months, the difference between the two treatment groups was not statistically significant ($p>0.05$). Besides, patients in whom the deposit disappeared on radiographs obtained higher increases in the Constant and Murley score ($p<0.001$).

Clinically, Loew et al., in a prospective study, reported significant improvement of symptoms in 14 out of 20 patients (70%) after two applications of 2,000 shock waves with an energy flux density of 0.3 mJ/mm^2 [25]. Radiologically, there were 7 cases of complete resorption and 5 cases of partial disintegration after a follow-up of 12 weeks. These results were much better than the data reported in the preliminary series reported by Rompe et al. in which complete elimination of the deposit was observed in only 15% of 40 patients who were treated once with 1,500 impulses with an energy flux density of 0.28 mJ/mm^2 [39].

Effects of different guidance methods

Localizing the delivery of ESWT, exactly focused on the calcific deposit, is a main factor that influences its outcome. In daily clinical practice, shock waves are usually focused on the painful area at the insertion of the tendon, the biofeedback method, and not focused with radiographic or ultrasound guidance [45]. Good success rates of ESWT have been reported if the shock waves are focused using fluoroscopy, but most patients are treated without fluoroscopic focusing [39].

Sabeti-Aschraf et al. suggested that ESWT for the treatment of calcific tendonitis should be carried out with a navigation system, if available [8]. The authors hypothesized that focused delivery on the calcium deposit by 3-

dimensional, computer-assisted navigation reveals superior clinical and radiographic outcomes compared with localization through patient-to-therapist feedback (locating the point of maximum tenderness through palpation by the therapist with feedback from the patient). In a prospective, randomized, single-blind study, 50 patients suffering from persistent shoulder pain for longer than 6 months, were divided into two groups of equal numbers (navigation group and feedback group). A total of three therapy sessions of constant low energy (1,000 impulses of 0.08 mJ/mm^2) focused shock wave therapy was administered in weekly intervals in both groups. The study results revealed a statistically significant improvement in the navigation group. In this group, 15 patients had excellent results, compared with 5 patients in the feedback group ($p<$ 0.001). Good results were recorded in 3 patients in the navigation group and 9 patients in the feedback group ($p=$ 0.041). In the navigation group, 6 calcium deposits disappeared and 9 altered, compared with 1 disappearance and 12 alterations in the feedback group. They also observed the best clinical results in patients with a complete dissolution of the calcium deposit 12 weeks after ESWT.

Similarly Haake et al. in a single-blind, prospective, randomized study, analyzed the effect of ESWT on calcifying tendinopathy of the shoulder focused on the calcified area or the origin of the supraspinatus tendon, in 50 patients [32]. The first group of patients received 4,000 impulses (positive energy flux density 0.78 mJ/mm^2) in two treatment sessions after receiving local anesthesia at the origin of the supraspinatus tendon, and the second group received ESWT at the calcified area. They found that ESWT was a highly effective treatment for calcifying tendinopathy of the supraspinatus muscle when it was focused precisely using fluoroscopic control at the calcific deposit ($p<0.05$).

It seems important to keep the focal spot constantly at the calcific deposit during the entire treatment. In some cases, the patient's arm has to be rotated slightly or flexed, enabling the clinician to aim exactly at the deposit and not affect other superimposed structures.

Effects on different grades of calcific deposits

Grade II (homogenous in structure with no defined border or inhomogeneous in structure with sharp outline) calcific deposits respond better to ESWT than grade I (homogenous in appearance and with well=defined borders) according to the Gartner classification. Krischek et al. in a prospective study, observed 50 patients for 1 year after one application of 3,000 shock waves with an energy flux density of 0.28 mJ/mm [46]. Radiologically, deposits were eliminated completely in 8 patients, whereas 21 patients had partial disintegration. According to the Gartner classification, they observed changes of the radiologic/morphologic features in 88% of grade II deposits, but in only 44% in Grade I deposits.

Duration of EWST effectiveness

Studies have shown that the effectiveness of the method is maintained for many years. Patients who obtained complete dissolution of calcium deposits after ESWT have a good clinical outcome with no recurrence of calcium deposit for at least 3 years.

Wang et al. determined the effectiveness, at 2- to 3-year follow-up, of shock wave therapy for calcific tendinitis of the shoulder, in a prospective, controlled, clinical study [47]. Thirty-one patients (31 shoulders), were treated with shock wave therapy, with 1,000 impulses at 14 kV, and observed for 24–30 months. The overall results in the study group were: 60.6% excellent , 30.3% good, 3.0% fair, and 6.1% poor ($p<0.001$). The symptom recurrence rate in the study group was 6.5%. Resorption of calcium deposits was complete in 57.6% of the study group, partial in 15.1%, and unchanged in 27.3% ($p<0.001$). Deposit fragmentation was seen in 16.7% of the patients. The length of time needed for the calcium deposits to be eliminated ranged from 2 weeks to 3 months. It was remarkable that none of the patients who obtained complete dissolution of calcium deposits showed any recurrence of calcium deposits at 2 years after shock wave therapy.

Comparison of ESWT method with other treatment options

Extracorporeal shock wave therapy has been compared with other common treatment methods. Pan et al. evaluated the therapeutic effect of ESWT on function and sonographic morphology of calcified deposits in shoulders treated for chronic calcific tendinitis, comparing ESWT with transcutaneous electric nerve stimulation (TENS) therapy, and investigated which types of calcium deposit effectively respond to ESWT [48]. In a randomized controlled study, 60 patients were included. The ESWT was delivered at 2 Hz with 2,000 shock waves and the energy levels ranged from 0.26 mJ/mm^2 to 0.32 mJ/mm^2, depending on the intensity, which was adjusted to the patient's tolerance. Patients who had received ESWT had better functional results and greater pain reduction than did those who had TENS therapy at 12 weeks' follow-up ($p<0.05$).

In another prospective randomized study, Rompe et al. compared the results in 29 surgically treated patients with results in 50 patients treated with shock wave therapy. They noted comparable symptoms between the two groups after 1 year. However, at 2 years, significantly improved results were noted in the patients who had undergone shock wave therapy ($p<0.001$). Compared with surgery, shock wave therapy is safe, cost-effective, and without the risks and complications entailed in surgery [23]. Haake et al., in a prospective randomized study, compared ESWT versus cobalt gamma rays and no statistically significant difference between the groups was found ($p>0.05$) [49].

Complications

Side effects of ESWT in the treatment of insertion tendinopathies usually include soft tissue lesions, because of cell damage after ischemic–reperfusion injury, vasoconstriction, and production of free radicals [50]. A list of local complications is shown in Table 2.

Local soft-tissue swelling, cutaneous erosions, and transitory reddening of the skin usually resolved spontaneously after 48 h, pain and small hematomas when an energy level between 0.04 and 0.22 mJ/mm^2 is used are the main complications after ESWT therapy [51].

The side effects of ESWT are clearly dose-dependent. Steinbach et al. reported that a local energy density of 0.3 mJ/mm^2 is the lowest threshold for the occurrence of severe vascular damage in animals' soft tissue [52].

It is obvious that patients treated with a higher energy level develop larger and more frequent hematomas than those who are treated with a lower energy level [42]. With a 3-fold increase in energy the occurrence of hematomas did not increase more than linearly from 7 to 19%. The appearance of hematomas after treatment with shock waves is explained by capillary disruption and consecutive extravasation of erythrocytes [53]. In order to avoid this complication continuous wave ultrasound and low energy ESWT have been favored for a long time [54].

Pain also correlates with the energy introduced into the tissue. With an increase in energy from 0.15 mJ/mm^2 to 0.44 mJ/mm^2, pain increased significantly. Patients treated with a low energy level experienced no pain or moderate pain. In contrast, patients treated with a high energy level, complained of feeling anything from discomfort up to considerable pain [42].

Table 2 Local complications after ESWT of shoulder calcific tendinitis

Complications
Soft tissue swelling
Cutaneous erosions
Reddening of the skin
Pain
Hematoma
Nerve lesion
Transient bone edema
Humeral head osteonecrosis

Although, ESWT is often used near articular cartilage, no severe side effects were found to affect these structures. By using MRI, no changes in muscular tissue in patients after ESWT of the shoulder were detected, applying an energy flux density of 0.28 mJ/mm^2, but in one patient, transient edema of the bone was reported [40].

Maier et al. found thickness of the tendinous insertion on MRI after ESWT of the shoulder [55].

Vaterlein et al. studied the effect of shock waves on normal rabbit articular cartilage and reported no changes in the cartilage on macroscopic, radiologic, or histologic examination at 0, 3, 12, and 24 weeks after administration of 2,000 pulses of shock waves at 1.2 mJ/mm^2 [56]. However, that amount of energy is much higher than is used clinically in any human studies.

In contrast, only two reports of articular cartilage damage after ESWT in humans have been published. Durst et al. reported a case of osteonecrosis of the humeral head after ESWT [57]. In that patient, osteonecrosis was diagnosed incidentally 3 years and 4 months after three sessions of extracorporeal shock wave lithotripsy with 1,600–1,700 impulses at each session at a level of 12–13 kV over a period of 1 month. But the authors could not be sure when the disease process had started. They suggested that ESWT might be harmful to the blood supply of the humeral epiphysis, especially if the deposit is located close to the ascending branch of the anterior humeral circumflex artery. In this case, care must be taken to avoid the intertubercular groove when targeting the shock wave at deposits of calcium.

Similarly Liu et al. reported another case of osteonecrosis, which was diagnosed with MRI 3 months after ESWT, but the authors could not completely exclude the possibility of idiopathic osteonecrosis in their patient [58]. The authors suggested that patients with a small anterior humeral circumflex artery may be more susceptible to the development of osteonecrosis after ESWT because of vascular damage.

Conclusion

In conclusion, ESWT for the treatment of calcific tendinitis of the shoulder seems to be an effective therapy, and is less traumatic than surgical techniques. However, larger prospective randomized studies and long-term assessment are needed to further document clinical improvement and associated sonographic features, before this procedure becomes popular for the treatment of calcific shoulder tendinitis.

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