Mini review

Bone healing induced by ESWT

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Summary

It has been at least two decades since the introduction of Extracorporeal Shock-Wave Treatment (ESWT) for the treatment of non-unions; despite conflicting opinions in the literature, it is recently achieving good results also in acute fractures. This paper reports Authors' clinical experience with electromagnetic shock-waves in the treatment of delayed unions and fresh fractures. Nonunion cases experienced remarkable successful results at an average of 8-10 weeks after ESWT; high success rate is been also found for the acute fractures. It can be concluded that this therapy constitutes an important aid in treatment of non-unions and can be useful also in fresh bone fractures.

KEY WORDS: Shockwaves, delayed union, fracture.

Introduction

Stimulation of bony union by means of various physical modalities has been widely used in clinical practice. Extracorporeal Shock Wave Therapy (ESWT) offers the most promise. It is based on the rationale that high speed sound causes lithotripsy and it was first used to crush kidney stones in 1980 (1). In 1986, Valchanov performed the first treatment of pseudoarthrosis with ESWT; his idea was to destroy the eburnated edges of the pseudoarthrosis and, at the same time, keep intact the periostium. That way, by preserving the osteogenic tissue in the periostium, rapid vascularisation and consolidation of the bone were achieved (2). Clinical applications followed successfully like so experimental studies that showed osteoblast stimulation to osteogenesis (3, 4).
We present our personal experience in the treatment of non-unions and fresh fractures with ESWT. The evolution of the results obtained during 7 years provides important data regarding indications, protocols of therapy, prognostic factors, percentages of the successes and future possible applications.

Materials and methods

Our series include 204 cases of pseudoarthrosis of different bony segments and 16 cases of fresh closed fracture of tibia treated by external fixation. In the treatment of the pseudoarthrosis we used a range of energy flow density (EFD) between 0,22 and 1,10 mJ/mm^2 as tolerated and we applied 4000 pulses by an electromagnetic device (Minilith SL1-STORZ). Following shock-wave therapy, non-union was immobilized with a plaster cast or plaster splint, even if this immobilization was not necessary when the pseudoarthrosis was treated with appropriate osteosynthesis devices without evidence of loosening upon clinical and radiological examination.
In fresh fractures, ESWT was performed within a month from the surgery of external fixation and the patients received prohibition to load on fractured leg. The EFD was between 0,07 and 0,17 mJ/mm^2 and we used this low EFD to induce a neoangiogenetic effect; the number of pulses was the same that we used for pseudoarthrosis.
The successful of these treatments was valued clinically and radiologically and the t-student test was applied to statistic analysis.

Results

Follow-up was between a minimum of 45 days and a maximum of 3 months. Bone union was achieved in 174 (85%) of non-unions and 16 (80%) of fractures.
In the treatment of pseudoarthrosis the best results were obtained both at high and at low EFD ($p < 0,05$). The bone segments showed consolidation as following: 100% in clavicle and metatarsus, 96% in ulna, 80% in femur and carpal scaphoid, 78% in humerus and tibia. Males (87%) had better results than females (83%), like so older than 60 years (89%) in comparison with younger (83%) (Figs. 1 and 2).
The results of shock-waves treatment of fresh fractures were compared with a control-group. We assigned fracture healing when it was possible recognize at least 3 on 4 bone cortex at plain radiograph. The average of the bone cortex were 3,25 in ESWT-group (Figs. 3 and 4) and 2,54 in control-group.
Local complications included petechiae and hematoma formation that resolved spontaneously.

Discussion

Shock-Wave (SW) is a longitudinal acoustic wave that travels through the water of body tissue at ultrasound speed. It is a single pressure pulse with a short needle-like positive spike lasting less than one microsecond at lower amplitudes (5). SW is known to have a "cavitation effect", which is the phenomenon of microbubble formation when the wave pass through water-tissue. When subjected to ultrasound, these bubbles undergo compression cycles of negative and positive pressure and oscillations, and this sonodynamic response results in secondary motions, high local shear stress in tissue, microstreaming and implosion (5, 6).

Figure 1 - Radiograph of delayed union of radius taken before ESWT.

Figure 2 - Forty-five days after ESWT, the radius radiography image shows the complete bone consolidation.

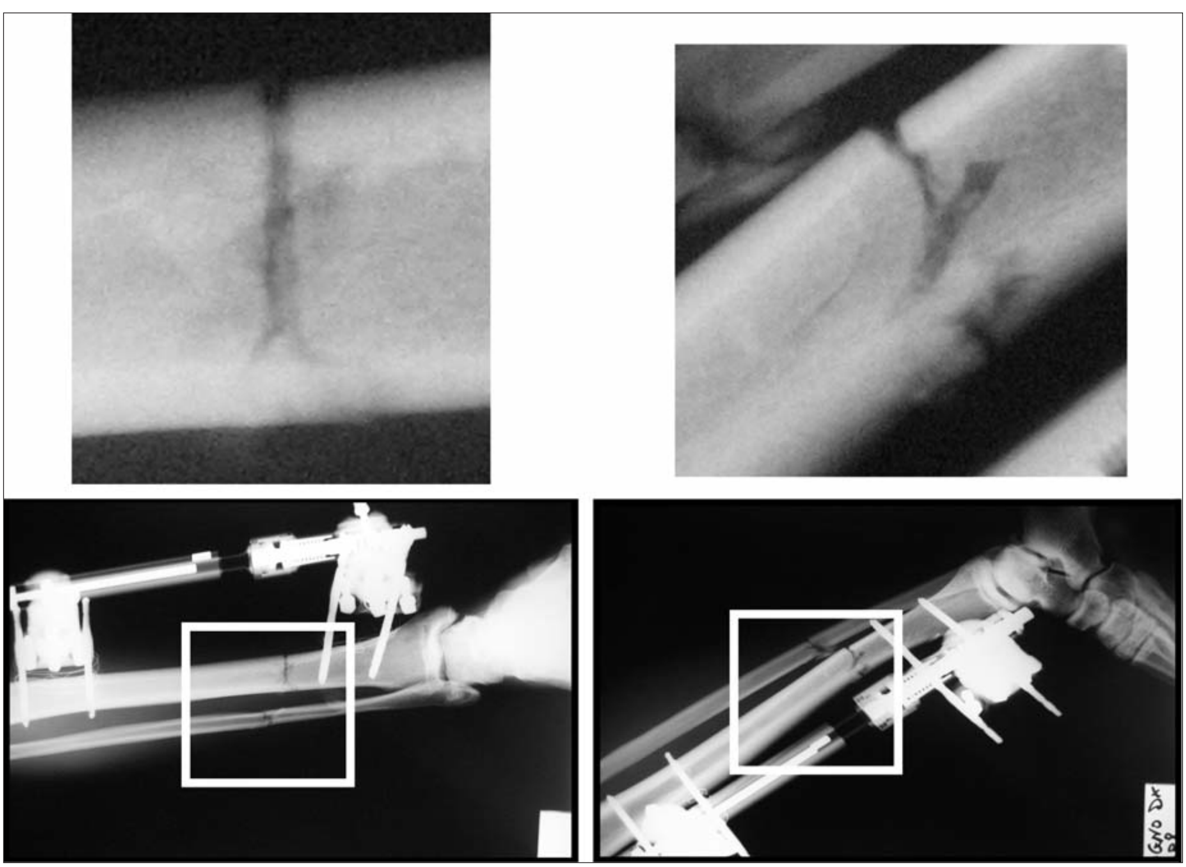

Figure 3 - Before ESWT, radiographic image of the fresh fracture of tibia shows the union only of 1 out of 4 bone cortex.

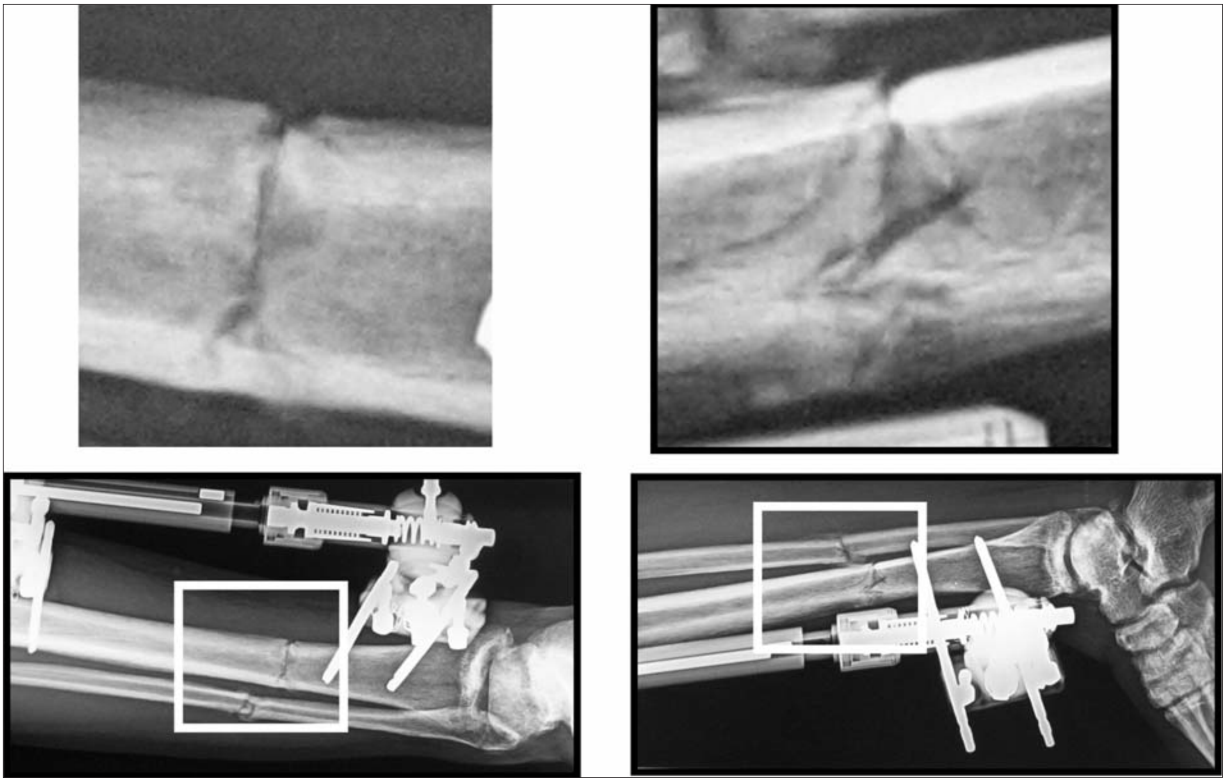

Figure 4 - Forty days after ESWT, radiograph shows the bone consolidation. Notice the formation of 3 out of 4 bone cortex of the fresh fracture of tibia.

Clinicians used ESWT successfully to break up kidney stones since 1980s and the high efficacy and few adverse effects associated with this treatment have made it the standard of care worldwide. It has also been shown to have a promising effect on the treatment of tendinopathies and on fracture healing (7, 8).
Unlike the treatment of kidney stones, the main therapeutic goal of orthopedic shock-wave application is not to destroy tissue but to stimulate tissue regeneration. Several studies are now researching the methods of bone-growth stimulation that are available for fractures and their scientific bases: many papers show that this treatment is effective in reducing the healing time of non-unions (9-11). High energy induces periosteal detachment and trabecular fractures with hemorrhages, which in turn stimulate callus formation and subsequent fracture healing (8, 12, 13); on the other hand, low-middle energy induces mesenchymal stem cell recruitment and differentiation into osteoblasts for bone formation (3, 14, 15).
The analysis of our results in pseudoarthrosis treatment offers useful information to the expert practitioner in the choice of patient and protocol to apply the ESWT successfully. The high EFD can be useful for atrophic nonunions in which shock waves produce non-surgical cruentation, instead the low EFD for ipertrophic ones in which this treatment allows angiogenesis and osteogenesis (16).
Our choice of a lower energy of ESWT in the treatment of fresh fractures is based on the rationale that ultrasound induces nitric oxide (NO) liberation at low energy, ever if the duration of NO liberation might be short after shock wave application (17). There is a link between NO and osteogenesis via the seven-day expression of the core binding factors cbfa1 (18). Consequently, our application of lower energy shock wave stimulates bone growth by nitric oxide production. Good outcomes in the fresh fractures suggest that shockwaves can improve the course of fracture healing increasing clinical applications of this therapy (14, 19).
According with literature data and our experience, the patients treated with ESWT showed good clinical and functional results. This technique represents a safe method of treatment with few complicances and good percentage of successful. The efficacy of shock-waves in the treatment of fractures and pseudoarthrosis must be based on the association of the biological stimulation of ESWT and the mechanical stabilization of fixation or cast. Therefore, ESWT can be consider the first choice in the management of fractures and pseudoarthrosis in association with an adequate mechanical stabilization of bone edges.

References

1. Chaussy C, Brendel W, Schmiedt E. Extracorporeally induced destruction of kidney stones by shock waves. Lancet. 1980 Dec 13;2(8207):1265-8.
2. Valchanov VD, Michailov P. High energy shock waves in the treatment of delayed and nonunions of fractures. Int Orthop. 1991;15: 181-4.
3. Martini L, Giavaresi G, Fini M, et al. Early effects of extracorporeal shock wave treatment on osteoblast-like cells: a comparative study between electromagnetic and electrohydraulic devices. J Trauma. 2006 Nov;61(5):1198-206.
4. Moretti B, Notarnicola A, Tamma R, et al. Osteoblast repair action induced by ESWT. 11th Congress ISMST, Juan Les Pins, Antibes, France, 5-7 June 2008. Abstracts-book: 42-43.
5. Apfel RE. Acoustic cavitation: a possible consequence of biomedical uses of ultrasound. Br J Cancer Suppl. 1982;5:140-6.
6. Maisonhaute E, Prado C, White PC, Compton RG. Surface acoustic cavitation understood via nanosecond electrochemistry.

Part III: Shear stress in ultrasonic cleaning. Ultrason Sonochem. 2002;9(6):297-303.
7. Wang, C-J. An Overview of Shock Wave Therapy in Musculoskeletal Disorders. Chang Gung Med J. 2003;26:220-32.
8. Bara T, Synder M. Nine-years experience with the use of shock waves for treatment of bone union disturbances. Ortop Traumatol Rehabil. 2007 May-Jun;9(3):254-8.
9. Valchanou VD, Michailov P. High energy shock waves in the treatment of delayed and nonunion of fractures. Int Orthop. 1991;15: 181-4.
10. Johannes EJ, Kaulesar Sukul DM, Matura E. High-energy shock waves for the treatment of nonunions: an experiment on dogs. J Surg Res. 1994;57:246-252.
11. Haupt G. Use of extracorporeal shock waves in the treatment of pseudoarthosis, thendinopathy and other orthopaedic diseases. J Urol. 1997;158:4-11.
12. Narasaki K, Shimizu H, Beppu M, Aoki H, Takagi M, Takashi M. Effect of extracorporeal shock waves on callus formation during bone lengthening. J Orthop Sci. 2003;8(4):474-81.
13. Bulut O, Eroglu M, Ozturk H, Tezeren G, Bulut S, Koptagel E. Extracorporeal shock wave treatment for defective nonunion of the radius: a rabbit model. J Orthop Surg (Hong Kong). 2006 Aug; 14(2):133-7.
14. Chen YJ, Wurtz T, Wang CJ, et al. Recruitment of mesenchymal stem cells and expression of TGF-beta 1 and VEGF in the early stage of shock wave-promoted bone regeneration of segmental defect in rats. J Orthop Res. 2004 May;22(3):526-34.
15. Aicher A, Heeschen C, Sasaki K, Urbich C, Zeiher AM, Dimmeler S. Low-energy shock wave for enhancing recruitment of endothelial progenitor cells: a new modality to increase efficacy of cell therapy in chronic hind limb ischemia. Circulation. 2006 Dec 19;114(25):2823-30.
16. Xu ZH, Jiang Q, Chen DY, et al. Extracorporeal shock wave treatment in nonunions of long bone fractures. Int Orthop. 2008; Apr 25. Epub ahead of print
17. Altland OD, Dalecki D, Suchkova VN, Francis CW. Low-intensity ultrasound increases endothelial cell nitric oxide synthase activity and nitric oxide synthesis. J Thromb Haemost. 2004;2(4):637-43.
18. Zaragoza C, López-Rivera E, García-Rama C, Saura M, Martínez-Ruíz A, Lizarbe TR, Martín-de-Lara F, Lamas S. Cbfa-1 mediates nitric oxide regulation of MMP-13 in osteoblasts. J Cell Sci. 2006; 119:1896-902.
19. Hsu RW, Tai CL, Chen CY, Hsu WH, et al. Enhancing mechanical strength during early fracture healing via shockwave treatment: an animal study. Clin Biomech (Bristol, Avon). 2003 Jul; 18(6):S33-9.