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● *Original Contribution*

EXTRACORPOREAL SHOCKWAVES *VERSUS* SURGERY IN THE TREATMENT OF PSEUDOARTHROSIS OF THE CARPAL SCAPHOID

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Abstract—The peculiar anatomical characteristics and precarious vascularization of the carpal scaphoid are responsible for a difficult healing of fractures and a fairly frequent subsequent evolution to pseudoarthrosis. Recently, extracorporeal shockwaves therapy (ESWT) has yielded encouraging results in the treatment of pseudoarthrosis of various bone segments. We report a retrospective study comparing the results of application of three sessions of shockwaves therapy (SW) with energy flux density (EFD) impulses of 0.09 (SD = 0.02) mJ/mm^2 ESWT emitted by an electromagnetic generator in 58 patients (group I) affected by pseudoarthrosis of the carpal scaphoid, with the results of surgical treatment consisting of stabilization and bone graft according to the Matti-Russe technique, performed in 60 subjects (controls, group II). There were no statistically significant differences in the mean duration of the pseudoarthrosis ($p = 0.46$), sex distribution ($p = 0.41$) and mean age at recruitment ($p = 0.95$) between the two patient groups. Posttreatment clinical-functional assessment, based on the Mayo Wrist Score, showed a significantly improved score, rising from 28–74.6 in group I already after 2 mo ($p < 0.001$), with 86.3% of the results judged as satisfactory or excellent; in group II the mean score rose from 27.5–74.2 after 2 mo, with 83.4% of the results judged as satisfactory or excellent ($p < 0.001$). At the same two-months follow-up (FU), radiographic consolidation was shown in 75.9% of patients in group I and 76.7% in group II. These improvements persisted at the subsequent controls at six and 12 mo in both groups. The Mayo Wrist Score and X-rays did not show statistically significant differences at the various FU visits in the two groups ($p > 0.05$). On the basis of our data, we can conclude that the results of ESWT are comparable with those of surgical stabilization and bone graft in the treatment of scaphoid pseudoarthrosis. In view of their minimal invasiveness, shockwaves should therefore be considered the treatment of choice of this disorder. (E-mail: angelanotarnicola@yahoo.it) © 2010 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Shockwaves therapy, Surgery, Scaphoid, Pseudoarthrosis.**

INTRODUCTION

The scaphoid is the carpal bone that is most commonly fractured because it plays the main role in maintaining wrist stability and in transferring compression loads from the hand to the forearm. In 1889, Cousin and Deston were the first to describe a scaphoid fracture as a typical lesion in young men, caused by trauma, generally in hyperextension of the wrist during sport (Krasin et al. 2001). Surgical treatment *ab initio* is reserved to those cases with clear signs of instability, *i.e.*, a diastasis >1 mm and involvement of both corticals. In other cases, conservative treatment is preferred, with immobilization for 4–6 weeks in a brachio-metacarpal plaster cast with the thumb included in the cast (Geoghegan et al. 2009). However, 10% of conservatively treated scaphoid fractures evolve to pseudoarthrosis because the prevalently articular nature of this bone (80% of the scaphoid surface is covered by joint cartilage) leaves little space for vascular supply from the radial artery, which guarantees only 70–80% of nourishment of the surface (Taleisnik and Kelly 1966; Gelberman and Menon 1980).

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The ideal treatment of scaphoid pseudoarthrosis has not yet been established and is still often controversial. Volar percutaneous cannulated screw fixation (Kim et al. 2010), dorsal percutaneous implantation of a headless compression screw (Slade et al. 2008), Acutrak screw or Herbert screw (Gregory et al. 2008) and synthes cannulated scaphoid screw and bone graft (Inaparthy and Nicholl 2008) are some of the treatments recently proposed to treat the scaphoid nonunion. Previously, casting and pulsed electromagnetic fields were postulated (Adams et al. 1992). We suggest that shockwaves (SW) could be helpful to heal the delayed fractured scaphoid (Bara and Synder 2007; Schaden et al. 2001; Moretti et al. 2009; Xu et al. 2009). On the other hand, some authors conclude that SW have no beneficial effect in fracture repair (Augat et al. 1995; Biedermann et al. 2003). Nevertheless, there is a general consensus that complete consolidation can be obtained by stabilizing the area and the district vascularization.

Aim of this retrospective clinical study was to compare the efficacy of extracorporeal shock waves therapy (ESWT) with that of a standard surgical procedure to treat pseudoarthrosis of the carpal scaphoid.

MATERIALS AND METHODS

From 2002–2008, at the Orthopedic Clinics of the University Hospitals of Bari and Naples, 350 patients were treated for scaphoid pseudoarthrosis by ESWT or standard surgery. Complete clinical and instrumental data at one-year follow up (FU) are available for 118 of these patients. All subjects had a previous history of wrist trauma in dorsiflexion, 91 after a fall and the other 27 during sports activity; the dominant limb was affected in 88.1% of the cases. In all patients, the acute fracture presented as stable (type A, according to Herbert's classification) (Krimmer et al. 2000) and was treated with brachio-metacarpal plaster cast immobilization for a mean period of 10 weeks (range 4 to 12 weeks), during which regular radiographic controls were made.

When the patients came to our observation, the clinical and X-ray picture showed scaphoid pseudoarthrosis (D1-D2-D3 according to Herbert's classification) (Krimmer et al. 2000). A diagnosis of scaphoid pseudoarthrosis was made in all cases that failed to show radiographic consolidation after at least 6 mo of conservative treatment, persisting for a further three months (Krasin et al. 2001).

Patients were offered two possible treatment options: surgery according to the Matti-Russe method or ESWT; 58 subjects preferred to undergo conservative treatment and were assigned to group I, whereas 60 chose surgery and were assigned to group II.

Patient monitoring was done by the same physician pretreatment and at two, six and 12 months post-therapy, on the basis of a clinical assessment using the Mayo Wrist Score (90 to 100 points excellent, 80 to 89 good, 60 to 79 satisfactory, <60 unsatisfactory) (Amadio et al. 1989) and an instrumental analysis by wrist X-ray on classic scaphoid projections.

The 58 subjects (53 males, 5 females) in group I had a mean age of 33.2 y and the mean time between the trauma and ESWT was 14.8 mo; in 10.3% of these subjects, the focus was localized at the proximal pole, in 27.6% at the distal pole and in the remaining 62.1% in the scaphoid body. Clinical assessment with the Mayo Wrist Score yielded a mean value of 28, classified as "unsatisfactory." In all patients, we checked to make sure there were no contraindications for SW such as a pacemaker, coagulopathy, neoplasia or infection in the district or pregnancy (Table 1).

SW were emitted by an electromagnetic generator equipped with an ultrasound imaging system (MiniLith-Storz, Switzerland). We applied a SW protocol in accordance with the treatments for bone disease as previously described in the literature (Tischer et al. 2008; Moretti et al. 2009). We performed three sessions at 72-h intervals, each consisting of 4000 impulses (Moretti et al. 2009). The energy flux density (EFD) was set at a mean of 0.09 (SD = 0.02) mJ/mm^2 (range 0.05 to 0.12 mJ/mm^2) (Tischer et al. 2008) depending on the patient's degree of pain tolerance. The ultrasound monitoring let us identify the anatomic site and to follow it during all the treatment. There were no findings from the B-mode ultrasound images during the ESWT.

Between each session, the arm was immobilized in a brachio-metacarpal sling, and at the end of the treatment cycle, a brachio-metacarpal cast with the thumb enclosed was fashioned and left until the first radiographic and clinical control, done after 60 d.

Group II consisted of 60 subjects (52 male, 8 female), mean age 33 y, with a mean interval between the trauma and the surgical treatment of 15.8 mo. In 11.6%, the focus was localized at the proximal pole, in 28.4% at the distal pole and in the remaining 60% in the body (Table 1). The surgical procedure was always performed by the same surgeon, adopting the Matti-Russe technique, with palm access to the wrist through an incision along the radial flexor of the carpus and longitudinal opening of the volar capsule. After removing the pseudoarthrosis manually with a Volkmann's spoon, a bone trench defect was created, perpendicular to the rim of the pseudoarthrosis, and the gap was filled with cortico-spongious bone tissue obtained from the homolateral olecraneum (block with spongious tissue and closure with a cortical plug like a fitted "lid"). Finally, the radio-scaphoid and radio-scaphoid-capitate ligaments were reconstructed.

Table 1. Epidemiological and clinical characteristics of the two patients groups: Data and statistical analysis

	n	Males	Females	Age (y) (mean; SD; range)	Proximal pole (%; *n*; CI)	Distal pole (%; *n*; CI)	Body (%; *n*; CI)	Duration of pseudoarthrosis (mo) (mean; SD; range)	Mayo Wrist Score (mean; SD; range)
Group I (ESWT)	58	53	3	33.19; 12.7; 16–65	10.3%; 6; 95% CI = 2.5–18.2	27.6%; 16; 95% CI = 16.1–39.1	62.1%; 36; 95% CI = 49.6–74.6	14.8; 6.99; 9–36	28;12.1;10–50
Group II (surgery)	60	52	8	33.05; 13.2; 16–65	11.6%; 7; 95% CI = 3.5–19.8	28.4%; 17; 95% CI = 16.9–39.7	60%; 36; 95% CI = 47.6–72.4	15.8; 7.52; 9–40	27.5 (SD = 12.2)
p-value	—	0.41		0.95		0.96		0.46	0.81

The arm was then immobilized in a brachio-metacarpal cast for 60 d.

We obtained informed consent from each person to receive each treatment. The study was approved by our university's ethics committee.

Student's *t*-test for independent samples was used for comparison of continuous variables, and 2 × 2 contingency tables and the chi-square test were used for categorical variables. The level of significance was set at $p < 0.05$. Data processing was done with Epi-Info 6.00 software (public domain software; Centers for Disease Control and Prevention, Atlanta, GA; World Health Organization, Geneva, Switzerland). Data are expressed as mean ± SD, range and confidence intervals (CI).

There were no statistically significant differences in the mean duration of the pseudoarthrosis (t = 0.72; $p = 0.46$), sex distribution ($\chi^2 = 0.66$; $p = 0.41$), anatomical localization ($\chi^2 = 0.73$; $p = 0.96$), mean age (t = 0.05; $p = 0.95$) and Mayo Wrist Score (t = 0.23; $p = 0.81$) between the two groups (Table 1).

RESULTS

In group I, at two-month FU, radiographic consolidation of the pseudoarthrosis was observed in 75.9% of the subjects (Table 2), whereas clinical assessment using the Mayo Wrist Score showed a significant improvement, the mean score being 74.65 (t = 19.5; $p < 0.001$) (Table 3). The results were scored as excellent in 19% of patients, good in 32.8%, satisfactory in 34.5% and unsatisfactory in 13.7% (Table 4).

At six-month FU, consolidation had occurred in 79.3% of the patients; clinical monitoring demonstrated persistence of the improvement, the mean score now being 77.41 (t = 21,4; $p < 0.001$). The result was excellent in 22.4% of the subjects, good in 34.5%, satisfactory in 32.8% and unsatisfactory 10.3%.

At the one-year FU, the X-ray consolidation had undergone no change in 79.3% of the successful cases; the mean clinical score was 77.58 (t = 20.8; $p < 0.001$) and the distribution in the four classes was the same as at the six-months FU (Fig. 1).

In group II, at the two-month FU, we observed radiographic consolidation of the pseudoarthrosis focus in 76.7% of the patients, whereas the clinical assessment with the Mayo Wrist Score demonstrated a significant improvement, with a mean score of 74.16 (t = 18.4; $p < 0.001$). The results were judged excellent in 21.7% of the cases, good in 31.7%, satisfactory in 30% and unsatisfactory in 16.6%.

At the six-month FU, radiographic healing was documented in 78.3% of the patients and the clinical assessment demonstrated the persistence of the improvement, with a mean score of 79.7 (t = 19.8; $p < 0.001$). Excellent

Table 2. Radiograph consolidation of the two patients groups at two, six and 12 months after the treatments: data and statistical analysis

Rx consolidation		Group I	Group II
2 mo	*n*	44	46
	%	75.9	76.7
	CI	95% = 64.8–86.9	95% = 65.9–87.4
	χ^2	0.01	
	p-value	0.91	
6 mo	*n*	46	47
	%	79.3	78.3
	CI	95% = 68.9–89.7	95% = 67.9–88.8
	χ^2	0.01	
12 mo	*n*	0.89	
	%	79.3	78.3
	CI	95% = 68.9–89.7	95% = 67.9–88.8
	χ^2	0.01	
	p-value	0.89	

Table 3. Mayo Wrist Score of the two patients groups at two, six and 12 months after the treatments: data and statistical analysis

Mayo Wrist Score		Group I		Group II
2 mo	Score	74.65		74.16
	SD	13.6		15.3
	Range	45–95		40–95
	t-test		0.18	
	p-value		0.85	
6 mo	Score	77.41		79.7
	SD	13.1		14.9
	Range	50–100		45–100
	t-test		0.19	
	p-value		0.84	
12 mo	Score	77.58		78.91
	SD	13.4		14.9
	Range	50–100		45–100
	t-test		0.5	
	p-value		0.61	

results were shown in 26.7% of the subjects, good in 28.3.%, satisfactory in 28.3% and unsatisfactory in 16.7%.

At one-year FU, no radiographic change had occurred in the successful cases and clinical monitoring with the Mayo Wrist Score showed a mean score of 78.91 (t = 20.7; $p < 0.001$). The results were excellent in 35% of the subjects, good in 25%, satisfactory in 23.3% and unsatisfactory in 16.7% (Fig. 2).

In conclusion, at the two-month FU, comparison of the results in the two groups (ESWT, group I *vs.* Surgery, group II) did not reveal significant differences either in regard to radiographic consolidation ($\chi^2 = 0.01$; $p = 0.91$) or the Mayo Wrist Score (t = 0.18; $p = 0.85$). Neither was there any difference at six months (X-ray: $\chi^2 = 0.01$, $p = 0.89$; Mayo Wrist Score: t = 0.19, $p = 0.84$) or at one year (X-ray: $\chi^2 = 0.01$, $p = 0.89$; Mayo Wrist Score: t = 0.5, $p = 0.61$) (Fig. 3) (Tables 2–4).

No complication arose in either group.

DISCUSSION

Delayed consolidation of the carpal scaphoid can be asymptomatic in the early stages and often goes unnoticed. Failure to institute timely treatment results in evolution to pseudoarthrosis, often with severe loss of bone tissue and collapse of the carpus. This failed or delayed consolidation of an acute fracture is attributable to the presence of the unfavorable scaphoid conditions for cell repair, namely a mechanical instability of the focus and poor or absent vitality of the bone ends caused by unsatisfactory locoregional vascularization (Frost 1989; Judet et al. 1958). Surgical treatment is advised, even if the clinical picture is not severely distorted, in view of the natural history of evolution of the pseudoarthrosis toward an overall arthritic degeneration of the entire wrist within 10 y. Among the various surgical options, the most commonly adopted are styloidectomy, scaphoid denerving, replacement with a scaphoid prosthesis, distal osteotomy of the radius, osteosynthetic repair (with a Herbert screw, *etc.*), metal osteosynthesis and transplantation, Murray's preparation and an autograft procedure, Matti's technique with cleansing and autograft by dorsal access and the Matti-Russe procedure for excavation and cortico-spongious autograft by volar access (Carpentier et al. 1995; Christadoulou et al. 2001; Inaparthy and Nicholl 2008; Fousek and Klézl 1999). In our patients treated with this last surgical procedure, the percentage of healing and satisfactory clinical results is in line with data in the literature (Gröner et al. 1995). We prefer the Matti-Russe method for three reasons:

1. Volar access saves the distal vessels and tubercle. Moreover, the scar is more esthetic and does not come in conflict with the sensitive radial nerve endings, which are highly abundant in the dorsoradial region.
2. The cortico-spongious autograft technique fully satisfies the biomechanical requirements for healing of pseudoarthrosis, because it offers both a mechanical stabilization function of the bone fragments as a result of the cortical bone graft fitted tightly into the trench, and a vascular and osteogenic biological function as a result of the ample addition of spongious tissue.
3. The method is simple to apply.

Options for nonsurgical treatment of scaphoid pseudoarthrosis include the use of magnetic impulses, electrostimulation or low-intensity ultrasound, although a long clinical course has been described after these procedures, resulting in further social and health service costs

Table 4. Clinical results of the two patients groups at two, six and 12 months after the treatments: data and statistical analysis

	(n; %; CI)	Group I	Group II
2 mo	Excellent	11; 19%; 95% CI = 8.9–29	13; 21.7%; 95% CI = 11.2–32.1
	Good	19; 32.8%; 95% CI = 20.7–44.8	19; 31.7%; 95% CI = 11.9–43.4
	Satisfactory	20; 34.5%; 95% CI = 22.2–46.7	18; 30%; 95% CI = 18.4–41.6
	Unsatisfactory	8; 13.7%; 95% CI = 4.9–22.7	10; 16.6%; 95% CI = 7.2–26.1
6 mo	Excellent	13; 22.4%; 95% CI = 11.7–33.1	16; 26.7%; 95% CI = 15.5–37.9
	Good	20; 34.5%; 95% CI = 22.2–46.7	17; 28.3%; 95% CI = 13.9–39.7
	Satisfactory	19; 32.8%; 95% CI = 20.7–44.8	17; 28.3%; 95% CI = 13.9–39.7
	Unsatisfactory	6; 10.3%; 95% CI = 2.5–18.2	10; 16.7%; 95% CI = 7.2–26.1
12 mo	Excellent	13; 22.4%; 95% CI = 11.7–33.1	21; 35%; 95% CI = 22.9–47.1
	Good	20; 34.5%; 95% CI = 22.2–46.7	15; 25%; 95% CI = 14–35.9
	Satisfactory	19; 32.8%; 95% CI = 20.7–44.8	14; 23.3%; 95% CI = 12.6–34
	Unsatisfactory	6; 10.3%; 95% CI = 2.5–18.2	10; 16.7%; 95% CI = 7.2–26.1

(Divelbiss and Adams 2001). Some authors suggest that it is better to treat delayed consolidation and pseudoarthrosis with SW because they provoke a stronger stimulation than ultrasound (Bara et al. 2000; Birnbaum et al. 2002; Schaden et al. 2001; Ikeda et al. 1999; Valchanov and Michailov 1991). SW are single acoustic impulses, produced by an electrohydraulic, electromagnetic or piezoelectric generator, focused by an acoustic lens or pressure peak from a reflection system onto the focal point of the target tissue. SW feature a rapid, short-lasting, high-pressure peak, followed by an exponential pressure drop. SW have broadband spectrum and their high-frequency component are attenuated when penetrating though the tissue (Rompe et al. 2001; Speed 2004; Wilner and Strash 2004). Physicians use the term of *energy flux density* (EFD) to illustrate the fact that SW energy ''flows'' through an area with perpendicular orientation to the direction of propagation. Its unit is mJ/mm^2. Rompe *et al.* (1998) classified the SW treatment on the basis of EFD: low (<0.08 mJ/mm^2), medium (<0.28 mJ/mm^2) and high (<0.60 mJ/mm^2). The EFD applied in clinical practice ranges from 0.001–0.4 mJ/mm^2 (Loew and Rompe 1998); at lower and medium EFD, nitric oxide (NO) is released, which has antalgic, angiogenetic and anti-inflammatory effects that are very useful in the treatment of various tendinopathies (epicondylitis, plantar fascitis, conflict of the shoulder syndrome, jumper's knee, *etc*.) (Loew and Rompe 1998; Maier et al. 2000; Daecke et al. 2002). Instead, a high EFD is applied to treat pseudoarthrosis localized in the femoral or tibial diaphysis or metaphysis, yielding a 72% success rate (Corrado et al. 1996; Delius et al. 1995; Schleberger et al. 1992; Valchanov and Michailov 1991). Starting from the assumption that the acoustic impedance of the crystals in kidney stones is similar to that of the hydroxyapatite crystals in bone, it has been demonstrated that SW passing through the pseudoarthrosis focus not only induce fragmentation of the diseased tissue by a direct mechanical effect, but also interfere with the bone tissue and neighboring soft tissues by inducing formation of a hematoma, followed by revascularization with local cell proliferation (Sistermann and Katthagen 1998; Rompe et al. 1998), which provides a strong osteogenic stimulus (Haupt 1997; Vogel et al. 1997; Moretti et al. 2008). This phenomenon, described as closed bleeding,'' is a consequence of the cavitation induced by passage of the shock waves through human tissues, *i.e*., a physical phenomenon consisting of the movement of gas bubbles or vapor inside a fluid (Apfel et al. 1981). This initially causes rupture of the bone lamellae and secondary local bleeding; rupture of the bonds among the tricalcium

Fig. 1. X-rays of a group I patient. (a) Pretreatment pseudoarthrosis of the scaphoid body is evident. (b) Two-month FU revealing ongoing consolidation of the fracture. (c) At one-year FU, the pseudoarthrosis is consolidated. The cycle shows the area of the pseudoarthrosis.

Fig. 2. X-rays of a group II patient. (a) shows the pretreatment localization of the pseudarthrosis in the scaphoid body. (b) The two-month FU, revealing ongoing consolidation of the pseudoarthrosis. (c) Consolidation of the pseudoarthrosis at one-year FU after surgery. The cycle shows the area of the pseudoarthrosis.

phosphate molecules, which are the inert hydroxyapatite macrocrystals, induces the formation of microcrystals that act as calcium-aggregating nuclei, creating active ossification process sites (Delius et al. 1995; Russo et al. 2001). This effect is useful in the treatment of pseudoarthrosis, in which the formation of hydroxyapatite crystals along the edge of the fracture prevents progression of the vascular buds coming from the fracture heads, thus reducing the blood flow and preventing the fibrous callus from transforming into bone tissue. The increased blood flow triggered by the hematoma, as well as the increased capillary permeability, increase the quantity of available oxygen and metabolites (Seidl et al. 1994). This condition is particularly helpful to treat pseudoarthrosis, because the low local oxygen and metabolic levels caused by the mechanical instability of the focus and the intrinsic characteristics of the diseased bone foster differentiation of the totipotent mesenchymal cells to chondroblasts, which produce fibrous tissue, rather than to osteoblasts (Schenk et al. 1994).

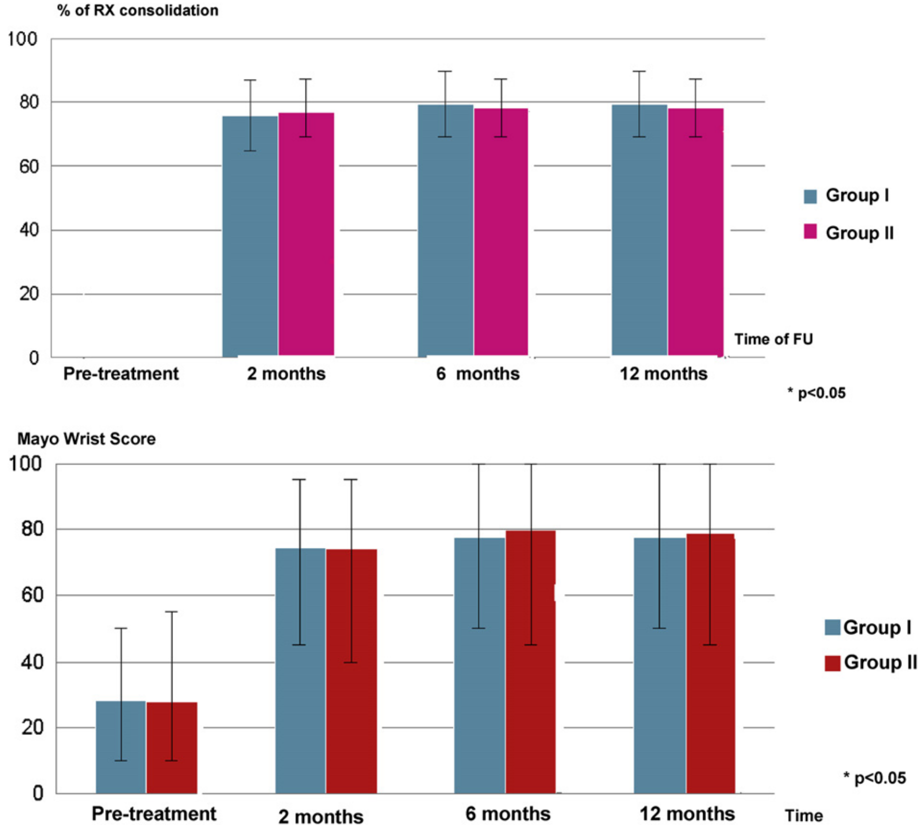

Fig. 3. The graph shows the values of radiographic consolidation (expressed as percentage and standard deviation) and of the Mayo Wrist Score (expressed as means and standard deviation). There are no statistically significant differences in the two groups at the three FU visits ($p > 0.05$).

The closed bleeding induced by the cavitational effect is important, therefore, but depends on the presence of an adequate 3-D bone structure, and hence on a cortex/medulla ratio that allows the formation of cavitation bubbles. The bone layer arrangement in the cortex does not leave enough space for cavitation bubbles to be generated, unlike the medulla, where there does seem to be enough space. For this reason, owing to the 3-D lamellar structure and the local water concentration, cavitation develops relatively easily in some bone segments, whereas in others a higher EFD is required, and in yet others no cavitation occurs even at high EFD. In the cortex, as stated before, cavitation cannot develop, but it occurs as soon as the SW reach the medulla, present up to a depth of 2.5 cm from the bone surface; if the cortex extends farther than 2.5 cm, it will not be possible to induce cavitation even at very high EFD (Delius et al. 1995). This is the reason that a high rate of failure has been recorded for the treatment of particular bone districts like the humerus, where the cortex component is preponderant at the diaphysis level and the medulla is denser than in other districts. The ideal bone for this treatment is the clavicle, because of its superficiality, small transverse diameter and the notable rarefaction of the bone layers, as well as the reduced cortical component. The tibia structure also features a suitable cortex-medulla ratio for this purpose (Russo et al. 2001).

In the scaphoid, even in normal conditions the cortex/medulla ratio is biased in favor of the former, so treatment with SW runs a high risk of failure. Instead, in our experience the application of medium-low SW EFD (that have a revascularizing biological effect, rather than a mechanical rupturing effect like higher levels) can induce a marked clinical and instrumental improvement, resulting in a comparable bone consolidation to the level obtained with the surgical procedure. These effects are particularly important in pseudoarthrosis foci with a very poor capacity for autonomous repair. They are induced by the local release of osteogenic factors such as NO, transforming growth factor beta 1 (TGF-β1) and bone morphogenic protein 2 (BMP-2) (Tamma et al. 2009; Wang et al. 2009), as well as the neoangiogenic factor vascular endothelial growth factor (Chen et al. 2004) caused by the SW. Previous research has shown that SW induce a hyperpolarization of the cell membrane, stimulating osteoblast proliferation (Martini et al. 2005) and favoring NO synthesis. As a result of the production of TGF- β1 and BMP-2, this promoted osteogenic differentiation of the mesenchymal stem cells (Wang et al. 2002). This phase also relies on the angiogenic stimulus induced by the SW, which seems to be particularly important during formation of the bone callus and its subsequent ossification (Wang et al. 2004).

Thus, the biological stimulus induced by SW appears to be more important than the mechanical effect, as pointed out in recent studies reporting that pseudoarthrosis patients failing to respond to SW treatment have low concentrations of bone turnover markers such as osteocalcin and bone-specific alkaline phosphatase (Cacchio et al. 2009). For this reason, we believe it is important to revise the classic SW therapy protocols proposed for the treatment of many skeletal districts, apart from the tibial and femoral diaphyses, in line with the idea that the response to the therapy is not only correlated to the mechanical bleeding effect induced by high EFD, but also to the angio- and osteogenic biological effects produced by medium-low EFD (Tamma et al. 2009; Wang et al. 2004).

In any case, it should be remembered that the metabolic effects must be supported by immobilization or stabilization of the bone segment for a suitable period (Bara and Synder 2007) to ensure an adequate mechanical stability of the focus.

In our work, as in other previous reports, many issues remain to be clarified regarding the SW therapy protocols, including the best total energy doses, number of sessions and total number of applications. Further multicentric studies and meta-analyses are needed to confirm the scientific validity of this technique and compare results with those obtained using different energy sources.

In conclusion, we believe that SW therapy, prescribed and administered in conformity to the aforementioned criteria, may offer a valid option for the treatment of the anatomical and biological problems posed by pseudoarthrosis of the scaphoid. We suggest that in view of its low invasiveness, SW therapy should be considered as the first-line treatment, reserving surgical stabilization to those cases that show no signs of clinical and radiographic improvement after application of a rational, correct treatment protocol.

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