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Research Article

Radial Pressure Waves: The Invisible Frontier Between Bone Healing and Nonunion

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Abstract

Introduction: Nonunion and delayed bone healing are common complications of fractures, particularly in long bones, with significant functional, social, and economic repercussions. Surgical treatment is considered the gold standard but often requires multiple procedures and entails high costs. In this context, radial extracorporeal shockwave therapy (rESWT) emerges as an outpatient, minimally invasive, and cost-effective alternative capable of stimulating bone consolidation.

Objectives: To evaluate the experience with rESWT in the management of nonunion and delayed bone healing. Specifically, to characterize patients according to demographic and clinical variables; to describe pain evolution using the visual analog scale (VAS); to compare radiological changes using the Montoya scale at one, three, and six months; and to determine patient functionality and satisfaction.

Methods: A descriptive, longitudinal, and prospective study was conducted in 15 patients treated at the Instituto Vivir Mejor between January 2022 and January 2025. The protocol included rESWT (BTL 5000 SWT Power, 4 bar, 15 Hz, 4,000 impulses, five weekly sessions), nutritional supplementation, and physiotherapy. Variables analyzed included sociodemographic characteristics, pain (VAS), radiological consolidation (Montoya scale), functionality, and satisfaction.

Results: Sixty percent of patients were young adults (19–40 years), with a predominance of males (53.3%). The most frequent diagnosis was delayed union (80%). Pain decreased significantly, from 33.3% with moderate pain at baseline to 93.3% pain-free at six months ($p < 0.001$). Radiologically, 93.3% reached Montoya grade 4 at six months ($p < 0.001$). Functionality improved progressively, with 100% of patients no longer requiring assistive devices and 93.3% reporting being “very satisfied” at six months.

Conclusions: rESWT, combined with nutritional support and physiotherapy, appears to be a safe, effective, and minimally invasive alternative in superficial nonunions and delayed consolidations. Its benefits include pain reduction, accelerated bone healing, improved functionality, and high patient satisfaction. Controlled, multicenter studies are recommended to confirm these findings and standardize clinical protocols.

Keywords: *Nonunion; Bone Healing; Radial Shockwave Therapy; Non-Invasive Therapy; Traumatology.*

Introduction

Nonunion and delayed consolidation are frequent complications after fracture surgery, particularly in long bones. It is estimated that, of the six million fractures treated annually, approximately 1.5 million present this problem [1]. Delayed consolidation is defined as the late healing of a fracture without radiological evidence within the expected timeframe, while nonunion corresponds to the complete failure of bone healing after six months post-trauma [2]. Several classifications are used for their evaluation, including the Montoya scale for tibial fractures and the Weber and Cech classification, which distinguishes atrophic, oligotrophic, and hypertrophic nonunion according to stability and vascularization [3,4].

The causes of these processes are multifactorial, including local factors such as fracture morphology and insufficient mechanical stability, which limit biological repair [2]. Surgical treatment continues to be considered the "gold standard"; however, it often requires multiple procedures and represents a high economic and functional burden for the patient. In this context, shockwaves emerge as a non-invasive alternative capable of stimulating bone consolidation and reducing complications [1].

Radial pressure waves (rESW) are acoustic impulses transformed into kinetic energy that, when applied to the fracture site, generate controlled microfractures and fragmentation of sclerotic bone, acting as an autologous graft. This mechanical stimulus triggers biological responses such as activation of osteoblasts and chondroblasts, release of growth factors (BMP-2, TGF-β, osteocalcin), differentiation of mesenchymal cells, and promotion of angiogenesis and biomineralization, optimizing bone repair [5]. Although considered superficial, rESW can reach up to 4 cm in depth, which is sufficient to stimulate consolidation in nonunions of superficial bones [6].

In Brazil, several studies have demonstrated the efficacy of high-energy focused shockwaves in the treatment of nonunion, with reported consolidation rates between 56% and 87%. Based on these results, and the evidence obtained in tendinopathies as well as in vitro and animal studies, some authors have initiated rESW protocols in nonunions of superficial bones [7-10]. Complementary research conducted in Lewisburg, Pennsylvania, suggests that radial waves are not limited to direct energy transfer to calcified tissue but also induce biomineralization processes, supporting their therapeutic potential in nonunions [8].

Based on the above, the present study aimed to evaluate the experience of using radial pressure waves in the management of nonunion and delayed consolidation. The specific objectives were: to characterize patients by age, sex, initial diagnosis, and affected bone; to describe pain levels using the visual analog scale (VAS) before and after treatment; to compare radiological changes at one, three, and six months after the intervention; and to determine patient functionality and satisfaction from the beginning to the end of treatment.

Nonunion and delayed consolidation represent a clinical challenge due to their functional, social, and economic impact. The search for less invasive, outpatient, and accessible treatments is essential to reduce complications and improve patients' quality of life. Radial pressure waves offer an innovative option that, if proven effective, could decrease the number of surgeries, shorten recovery times, and reduce hospital costs, becoming a complementary tool to traditional management. This study seeks to provide clinical evidence on the use of radial pressure waves as a therapeutic alternative in nonunion. If its efficacy is confirmed, this technique could reduce treatment-associated costs, limit the need for multiple surgeries, and shorten recovery times, offering an outpatient, minimally invasive, painless, safe, and cost-effective procedure.

Materials and Methods

This is a descriptive study, with a non-experimental, longitudinal, and prospective design. The population consisted of patients treated in the Traumatology and Orthopedics clinics of the Instituto Vivir Mejor, during the period from January 2022 to January 2025.

The sample was non-probabilistic, deliberate, and voluntary, comprising 15 patients who met the following inclusion criteria: patients diagnosed with delayed consolidation or nonunion, without clinical or radiological evidence of infection, bone defect smaller than 5 mm, and mechanically stable fracture site. Patients were excluded if they presented a localized tumor in the treatment area, were pregnant, were taking anticoagulants, had open physes, fracture stabilization failure, or bone defect greater than 5 mm.

Informed consent was obtained from all patients, explaining the procedure of radial shockwave application, nutritional and physiotherapeutic support included in the protocol, and possible adverse effects. Data were collected through direct observation, participation, and interviews, using a registration form designed by the researchers, which included variables such as age, sex, affected bone, type of injury, function of the affected limb, bone consolidation according to the Montoya classification, and degree of satisfaction.

Prior to application, a comprehensive protocol was designed:

1. Radial shockwave therapy: Each session lasted approximately 15 minutes, applied to the area of delayed consolidation or nonunion, determined by physical examination and radiological studies, using fixation material or coins for calibration. No hospitalization or anesthesia was required. A BTL 5000 SWT Power device was used, with a 12 mm applicator, frequency 15 Hz, intensity 4 bar, and 4,000 impulses divided across four points, moving the applicator along the fracture or nonunion line, totaling five weekly sessions [Fig. 1]. Clinical and radiological follow-up was performed at 1, 3, and 6 months, using the Montoya scale (Grade 0 to IV).

Figure 1. *Application of Radial Pressure Waves: A. Radial shockwave device BTL 5000 SWT Power with protocol settings. B. Area marking. C. Application of rESWT.*

2. Specific nutritional support: Supplementation with vitamin C (collagen and bone matrix synthesis), magnesium (cofactor for bone mineralization and vitamin D activation), vitamin D (calcium homeostasis and osteogenesis), omega-3 (anti-inflammatory and pro-angiogenic effect), and probiotics (nutrient absorption and inflammation modulation).

3. Supervised physiotherapy: Provided by professionals with certified experience in shockwave techniques and bone healing, aimed at maintaining joint mobility, preventing stiffness, promoting progressive loading, and stimulating bone regeneration through strengthening exercises and functional rehabilitation.

Data were organized in Microsoft® Excel 2016 and analyzed using descriptive statistics and statistical tests (Mann–Whitney and Chi-square). Significance level was set at $p < 0.05$. The study was approved by the Ethics Committee of the Instituto Vivir Mejor.

Results

A total of 15 patients with nonunion and delayed consolidation were included, with ages ranging from 19 to 70 years. The mean age was 39.3 ± 12.4 years, with a median of 30 years. The largest proportion of patients (60%, 9 cases) were in the 19–40 age group, indicating a higher concentration of cases among young adults.

Table 1. Characterization of patients included in the study. Experience with rESWT in the management of nonunion and delayed consolidation.

Age (years)	f	%
19 – 40	9	60
41 – 67	6	40
$\overline{X} \pm Es$	39,3 años ± 12.4	
Female	7	46,7
Male	8	53,3
Diagnosis	**f**	**%**
Delayed union	12	80,0
Oligotrophic nonunion	2	13,3
Atrophic nonunion	1	6.7
Affected bone	f	%
Proximal tibia	2	13,3
Mid-diaphyseal tibia (1/3 middle)	1	6,7
Distal femoral diaphysis (1/3 distal)	1	6,7
Proximal femoral diaphysis (1/3 proximal)	3	20,0
Proximal femoral diaphysis (1/3 proximal)	2	13,3
Patella	1	6,7
Distal diaphyseal tibia (1/3 distal)	2	13,3
5th metatarsal	2	13,3
Proximal toe phalanx	1	6,7
Total	**15**	**100**

Source: Data from the study (Chávez M, et al., 2025).

Regarding sex, males predominated (53.3% = 8 cases). The most frequent diagnosis was delayed union in 80% (12 cases). The most commonly affected bone was the proximal femoral diaphysis (20% = 3 cases), followed by the proximal tibia, mid-diaphyseal tibia, mid-diaphyseal humerus, and 5th metatarsal (2 cases each).

Table 2. Pain assessment using the Visual Analog Scale (VAS) before and after rESWT in the management of nonunion and delayed consolidation.

Time point	**Baseline**		**1st most**		**3rd most**		**6th most**	
Pain level	**f**	**%**	**f**	**%**	**f**	**%**	**f**	**%**
Absent	0	0	6	40	13	86,7	14	93,3
Mila	5	33,3	5	33,3	2	13,3	1	6,7
Modérate	5	33,3	4	26,7	0	0	0	0
Severe	5	33,3	0	0	0	0	0	0
Total	**15**	**100**	**15**	**100**	**15**	**100**	**15**	**100**
Median (range)	2 (3 – 8)		0,87 (1 – 6)		0,13 (1 – 3)		0,07 (0 – 1)	

Source: Data from the study (Chávez M, et al., 2025).

Pain assessment showed a progressive and significant decrease after rESWT, from moderate pain (33.3%) at baseline to absence of pain in most patients at six months (93.3%). The mean pain score was reduced from 2.0 to 0.07, with a significant association between pain level and study timepoint (χ^2 = 15.33; df = 3; p = 0.0016), reduction in VAS median (t = 4.60; p = 0.0009), and increase in the percentage of pain-free patients (Z = 8.48; p = 0.0001).

Table 3. Radiological changes after rESWT at 1, 3, and 6 months in the management of nonunion and delayed consolidation (Montoya scale).

Timepoint	Baseline		1st most		3rd most		6th most	
Montoya grade	**f**	**%**	**f**	**%**	**F**	**%**	**f**	**%**
1	7	46,7	2	13,3	0	0	0	0
2	8	53,3	9	60	2	13,3	0	0
3	0	0	4	26,7	6	40	1	6.7
4	0	0	0	0	7	46.7	14	93,3
Total	**15**	**100**	**15**	**100**	**15**	**100**	**15**	**100**

Source: Data from the study (Chávez M, et al., 2025).

Radiological consolidation according to the Montoya scale [Fig. 2] showed progressive and statistically significant improvement (χ^2 = 18.67; df = 3; p = 0.0004). At baseline, grade 1 (46.7%) and grade 2 (53.3%) predominated, while at three months, grades 3 and 4 increased (40% and 46.7%, respectively), and at six months most patients achieved grade 4 (93.3%). A significant difference was also observed in grade 1 consolidation rates from baseline to six months post-rESWT (Z = 4.24; p = 0.0001).

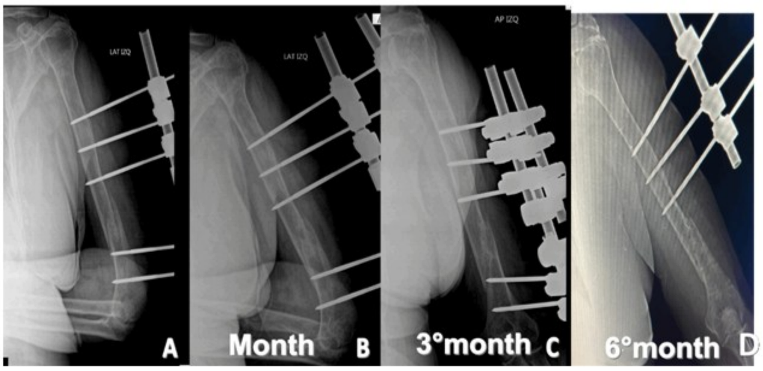

Figure 2. *Radiological follow-up: A. Baseline image before treatment. B. One month after rESWT. C. Three months after rESWT. D. Six-month follow-up after rESWT.*

Table 4. Patient functionality and satisfaction after rESWT at different follow-up stages.

Timepoint	Baseline		1st most		3rd most		6th most	
Funcionality	**F**	**%**	**f**	**%**	**F**	**%**	**f**	**%**
With assistive devices	11	73,3	6	40	3	20	0	0
Without devices	4	26,7	9	60	12	80	15	100
Satisfaction	**F**	**%**	**f**	**%**	**F**	**%**	**f**	**%**
Null	0	0	2	13,3	0	0	0	0
Dissatisfied	15	100	0	0	0	0	0	0
Satisfied	0	0	13	86,7	1	6,7	1	6,7
Very satisfied	0	0	0	0	14	93,3	14	93,3
Total	**15**	**100**	**15**	**100**	**15**	**100**	**15**	**100**

Source: Data from the study (Chávez M, et al., 2025).

Functionality showed progressive improvement, with most patients requiring assistive devices at baseline (73.3%) and the majority being device-free at the third and sixth month (80% and 100%, respectively), which was statistically significant (χ^2 = 3.56; df = 1; p = 0.0300) [Fig. 3]. Similarly, satisfaction increased from "dissatisfied" at baseline (100%) to "very satisfied" at six months (93.3%), with a significant association (χ^2 = 18.67; df = 2; p = 0.0001) and significant changes in the percentage of patients without assistive devices (Z = 2.84; p = 0.0046) and very satisfied (Z = 8.48; p = 0.0001).

***Figure 3.** Radiological follow-up and use of assistive devices: A. Baseline radiograph before rESWT, showing use of orthopedic devices. B. Six-month follow-up radiograph, showing bone consolidation and absence of assistive devices.*

Discussion

In our prospective, longitudinal, non-experimental series with radial extracorporeal shockwave therapy (rESWT) (n = 15), clinically relevant improvements were observed at six months in pain (93.3% asymptomatic according to VAS), radiological consolidation (93.3% Montoya grade 4), and functionality/satisfaction (100% without assistive devices; 93.3% "very satisfied"). rESWT at 4 bar, 15 Hz, 4,000 impulses, applied at four points during five weekly sessions, effectively targeted superficial foci (≤ 3–4 cm), promoting bone stimulation, further enhanced by the presence of osteosynthesis material. Preclinical studies in vitro and in animals support the ability of radial shockwaves to stimulate bone consolidation [1–3].

Radiographically, most patients presented grade 1 before intervention and grade 4 at six months, with a significant association between study timepoint and consolidation grade. Functionally, by the third month most patients were without assistive devices (80%), and there was a significant increase in "very satisfied" patients from baseline to six months. To date, no previous studies have evaluated these outcomes using the Montoya scale or functionality as an associated endpoint.

Comparatively, Kertzman et al. (2017, 2021) reported clinical-radiological success rates of 70–80% in superficial bones treated with three weekly sessions of rESWT (3,000 impulses, ~0.18 mJ/mm^2), without anesthesia [4,5]. Our results exceed these figures, likely due to the higher cumulative dose, predominance of delayed unions versus atrophic nonunions, and standardized co-interventions (nutrition and physiotherapy). The prospective series by Graziano and Michelini (2025) reported 76.4% consolidation at nine months and functional improvement in 17 patients treated with six ultrasound-guided sessions [11]. We concur on the safety and efficacy of rESWT in superficial nonunions; our higher success rates at six months may be explained by differences in casemix, co-interventions, and evaluation criteria (Montoya vs. radiographic + clinical union).

Although no studies directly assess the combination of nutrition and rESWT, existing evidence suggests that nutritional optimization may potentiate the effects of rESWT in bone healing. For example, vitamin D and calcium are essential for bone mineralization, while protein intake is crucial for extracellular matrix synthesis. rESWT, in turn, stimulates callus formation and osteoblastic activity. Therefore, adequate nutritional support could enhance treatment response to rESWT, reduce the risk of nonunion, and accelerate functional recovery [13–15].

Radial extracorporeal shockwave therapy (rESWT) emerges as an invisible frontier between bone repair and nonunion, offering a safe and effective approach that activates biological consolidation processes, even in cases of delayed union.

Conclusion

Our series shows that, when combined with nutritional support and structured physiotherapy, rESWT enhances osteogenesis, accelerates functional recovery, and reduces pain, transforming difficult-to-heal fractures into successful clinical outcomes. This non-invasive approach redefines traditional therapeutic boundaries and suggests that rESWT may become a central tool in the management of delayed unions and nonunions. Nevertheless, randomized controlled trials are required to optimize dosing, isolate effects from co-interventions, and confirm its true potential as a catalyst for bone repair.

Conflict of Interest

The authors declare no conflict of interest.

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