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CONTENTS

INTRODUCTION

Historical background

Sergio Gigliotti

The effects of shock waves on the human body were first observed during World War II: extensive areas of tissue destruction were found in the lungs of shipwreck survivors who had died due to depth charges, despite the absence of external signs of trauma.

However, it was not until the late 1960s that the interactions between shock waves and animal biological tissues were clarified, thanks to a program funded by the West German Department of Defense: it was demonstrated that high-energy shock waves propagated within the body, causing minimal effects when passing through muscles and adipose tissue. Furthermore, it was found that water and gelatin were the best transmission media for shock waves due to their acoustic impedance being highly similar to that of subcutaneous tissues. Conversely, the most significant biological effects occurred at the interfaces between structures or tissues with high acoustic impedance differences. These studies led to the realization that kidney stones could be fragmented by shock waves, and confirmation of this *in vitro*, prompted the German Department of Research and Science to finance a new research program in 1974 in order to explore possible applications in humans. In 1980, the first patient with kidney stones was experimentally treated with a prototype lithotripter developed by Dornier. Over the following three years, excellent results obtained both *in vitro* and *in vivo* led the company to commercialize the first immersion-bath lithotripter with radiographic localization. This device was installed in Stuttgart in 1983 for the treatment of kidney stones.

In 1985, the first treatment for gallstone disease was performed, and over the following decade, more than two million patients worldwide were treated for lithiasis. Meanwhile, technological advancements led to the development of tub-free lithotripters with dry coupling via water balloons and ultrasound localization. These innovations made the equipment significantly more versatile and open to other clinical applications. In 1988, Valchanov and Michailov in Bulgaria successfully applied shock waves to human nonunion fractures, publishing their results in 1991. Subsequently, numerous scientific publications emerged in the early 1990s,

Principles of physics of shock waves

Paolo Buselli

A shock wave is an acoustic wave with an impulsive characteristic that propagates through materials in various directions. It is characterized by a progression of its pressure peak, followed by a phase of pressure depression, and eventually returns to the pre-existing equilibrium conditions. The propagation characteristics of the pressure wave are similar to those of any other acoustic wave, following the laws of physics. Its intensity at the point of generation progressively diminishes, depending on the properties of the medium or media through which it propagates.

Table I Acoustic characteristics of different tissues (Source: modified from Dahmen et al.)

Tissue	**Density** (g/cm^3)	**Sound speed** (m/s)	**Acoustic impedance** ($g/cm^2s)10^{-5}$
Water	1	1492	1.49
Fat	0,9	1476	1.37
Muscle	1.06	1630	1.72
Cortical bone	1.8	4100	7.38
Iron	7.96	5100	40.00

The propagation speed of a shock wave, like that of any acoustic wave, depends on the acoustic impedance of the medium it traverses (table I). The mechanical properties of tissues, such as elasticity and compressibility, influence the propagation velocity. Acoustic impedance (Z) is defined as the product of the density of the medium (ϱ) and the speed of sound (C):

$$Z = \varrho C$$

As a shock wave propagates through the human body, it undergoes modifications depending not only on the impedance characteristics of each individual tissue but also on the sequence of tissues it traverses and the variations in their impedance. Following the laws of physics, the following phenomena occur:

- absorption of the wave (resulting in a reduction of its intensity);
- reflection when encountering tissue with different impedance;
- refraction when encountering tissue with different impedance.

These phenomena are influenced by the specific characteristics of the acoustic wave and the properties of the medium encountered. Consequently, the penetration of the pressure wave as it progresses through the body to reach the treatment target, inevitably depends on the physical differences among skin, fat, muscles, and bone. It also

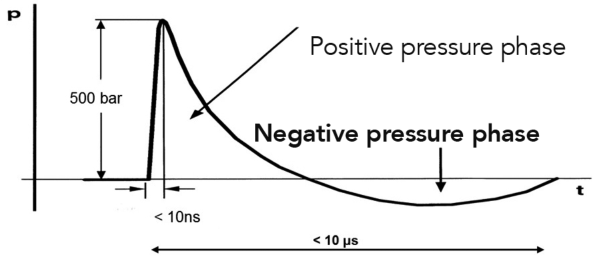

Figure 1 Schematic representation of the pressure curve behavior of focused shock waves

depends on the application method of the wave generator and the type of acoustic wave used.

When considering acoustic waves more generally and examining the specific behavior of shock waves, we can distinguish several types of sound waves based on their particular and unique behavior.

- *Ultrasound*: cyclic waves with positive and negative phases, defined by parameters such as frequency and amplitude. Ultrasound is characterized by a frequency of more than approximately 16,000 oscillations per second. This type of acoustic wave is widely used in medical applications, both therapeutic (ultrasound therapy) and diagnostic (ultrasound imaging).
- *Infrasound*: regular waves with positive and negative peaks that may have a sinusoidal shape. Defined by frequency, amplitude, and waveform, this type of acoustic wave is typical of sound and is used in vibratory stimulation. Shock waves fall within this category.

Shock waves are internationally defined as impulsive waves characterized by a rapid positive phase (less than 10 ns) with high amplitude (greater than 500 bar), followed by an exponential decrease to a modestly negative pressure value, and a subsequent stable return to normal ambient pressure levels.

The overall duration of the shock wave period must be short (within 10 μs). The next wave is typically generated after the previous wave returns to its resting position (schematically illustrated in figure 1).

Shock waves can thus be considered mechanical waves with distinctive physical characteristics.

During propagation, shock waves create a disturbance that locally alters the intermolecular distances of the medium. In the human body, the propagation characteristics are diverse and complex. Structures such as cellular membranes, which are only a few microns thick due to their multilayered molecular composition, are subjected to extremely high-pressure gradients caused by the transit of shock waves. These are followed by tensions resulting from sudden pressure differences at the front and rear of the cellular membranes, generating significant tensile forces.

GENERAL ASPECTS

Indications and contraindications of shock wave therapy

Sara Messina

Shock wave therapy, after its initial use in urology for lithotripsy, has expanded its applications to many musculoskeletal and bone-related conditions. In recent years, thanks to its role in regenerative therapies, it has also been utilized in andrology and wound care. More recently, it has found applications in cardiological and neurological pathologies.

The International Society for Medical Shockwave Treatment (ISMST) published a Consensus Statement in October 2016, later revised in June 2017, analyzing and classifying clinical recommendations for various conditions treated with shock waves. This Consensus Statement was adopted by the Italian Society for Shock Wave Therapy (SITOD) in 2019, with some modifications to accommodate the specificities of the Italian healthcare system.

In this document, pathologies were grouped based on the scientific evidence available in the literature and the different therapeutic approaches. These include conditions routinely treated with shock waves, those requiring specialized expertise, and experimental indications.

The indications can be divided into four categories:

- standard indications, supported by validated scientific evidence;
- indications based on clinical experience, widely used despite the absence of specific validated scientific evidence;
- exceptional indications, reserved for expert operators and applied outside common practice;
- experimental indications, for emerging or investigational applications.

Indications approved as "standard"

For medical conditions within this category, particularly chronic tendinopathies, shock wave therapy is the first line treatment, especially in cases where other conservative therapies have failed to produce results.

Within the standard indications, the following categories can be distinguished: chronic tendinopathies at the tendon or muscle-tendon junction, bone pathologies, and skin pathologies.

Iliotibial band tendinopathy (runner's or cyclist's knee) is an inflammatory condition affecting the iliotibial band, which is the distal part of the iliotibial tract that stabilizes the anterolateral aspect of the knee. Predisposing anatomical factors include varus tibia, prominent lateral femoral epicondyle, lower limb length discrepancy, and a tendency for foot pronation.

Tibial periostitis affects the periosteal membrane of the tibia medially, in areas where the soleus and posterior tibial muscles insert. It can result from excessive strain on these tendons due to excessive pronation during foot strike. The localization of pain is well-defined yet broad.

Tendinopathies of the leg-foot system (Achilles tendinopathy and plantar fasciitis) are addressed in specific chapters. As for bone-related pathologies, the sports context can involve particular conditions associated with alterations in the physiological state of the bone.

Stress fractures are commonly observed at the level of the tibia, affecting runners, soccer players, and military, or at the level of the metatarsal bones, more frequently in dancers and walkers. The advantage of the proposed protocols lies in the possibility of continuing training activities even during the therapeutic cycle. Notably, Albisetti described the treatment of dancers affected by this type of bone pathology (fig. 1).

Bone bruising (bone marrow edema), seen as a sequela of direct trauma, evolves into an inflammatory condition of the traumatized bone portion, manifesting as pain during specific load-bearing movements and reducing performance capabilities (fig. 2). Shock wave therapy is proposed to restore physiological metabolic and vascular condition in the bone.

Figure 1 X-ray image of a stress fracture of the fifth metatarsal

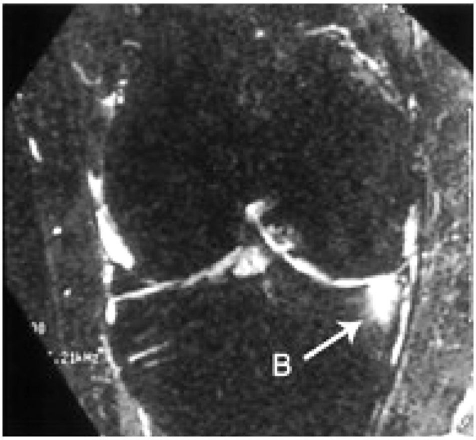

Figure 2 MRI image of a tibial contusion

Figure 3 Imaging of juvenile osteochondrosis of the knee

Juvenile osteochondrosis, despite the presence of growth plates being considered a contraindication, has seen some authors proposing the use of shock wave therapy to treat juvenile osteochondrosis, particularly in cases of Osgood-Schlatter disease. The aim is to promote the consolidation of the anterior tibial apophysis (fig. 3).
Sequelae of osteochondrosis, particularly at the calcaneal insertion of the Achilles tendon in Haglund's disease, often present with tendon inflammation following juvenile osteochondrosis (fig. 4). In these cases, shock wave therapy can reduce inflammation and improve symptoms, but it does not address the underlying cause. Thus, the therapeutic proposal appears more symptomatic than resolutive and should be evaluated in relation to the athlete's specific needs.

Figure 4 MRI image showing the outcome of Haglund's deformity

Additional degenerative and post-traumatic conditions also deserve attention in sports medicine and can benefit from shock wave therapy. These include post-traumatic fibrotic or calcific developments in tendons or muscles. Two of the most frequent conditions are discussed below.

Distractive musculo-tendinous injuries often result from elongation trauma, leading to the organization of affected muscle or tendon portions and associated hematoma. These conditions frequently leave behind a loss of elasticity in the muscle or tendon, causing recurring discomfort when the specific anatomical region is subjected to tension. The application of shock wave therapy aims to restore the extensibility and elasticity of the affected area.

Myositis ossificans is a consequence of muscular hemorrhagic infiltration caused by contusive or sharp trauma. The organization of residual hematoma and the development of local inflammatory phenomena lead to stiffness in the musculo-fascial system, resulting in severe functional limitations. This pathological condition is addressed in detail in a dedicated chapter.

Specificity of shock wave therapy

As previously mentioned, scientific literature has not yet devoted significant resources to analyzing the effects of shock wave therapy on the specific issues related to sports pathologies. The needs and objectives of treating athletes do not always align with the intervention strategies primarily focused on chronic conditions, which are well-documented in literature. However, it is worth noting certain specificities that should be considered when approaching the therapeutic classification with four progressive levels of the ossification process:

- compact bone islands in the soft tissues;
- bone spurs with a gap greater than 1 cm between them;
- bone spurs with a gap less than 1 cm between them;
- a complete bony bridge between joint surfaces.

To complement radiographic diagnostics, MRI or 3D CT scans may be useful in specific cases to provide a clearer view of the ossification (figs. 2 and 3). Bone scintigraphy can demonstrate increased tracer uptake in the affected joint and the ossified area, both of which indicate ongoing metabolic activity and bone remodeling.

Figure 2 MRI image of POA

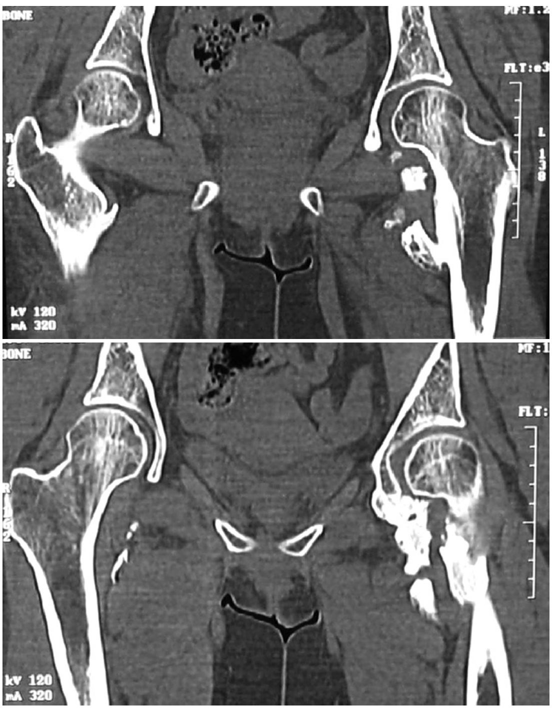

Figure 3 MRI image of POA

Medical treatment and prophylaxis

Attempts at prophylaxis using various drugs have not yielded positive results, except for indomethacin (75-100 mg/day), though there is no clear evidence in the literature of its ability to prevent or reduce negative progression. Better results have been observed with prophylaxis in high-risk patients undergoing hip replacement surgery through the administration of a single radiotherapy session within 24-48 hours post-surgery. However, even this lacks significant evidence.

At the time of diagnosis, during the early phase of the ossification process, various therapeutic interventions have been traditionally proposed, including ultrasound, hyperthermia, iontophoresis, Roentgen therapy, local corticosteroid injections, and chelation therapy with tetrasodium etidronate. None of these have demonstrated scientific evidence of efficacy. Two recent studies by Oberberg (2021) and Willburger (2022) report positive results for prophylactic treatment with etoricoxib.

Surgical treatment

Surgical treatment involves the removal of the ossification, though it is not always straightforward to perform. If performed during the active phase of the ossification process (indicated by elevated alkaline phosphatase levels and positive bone scintigraphy), the recurrence rate is very high. If carried out after the stabilization of heterotopic ossification, the recurrence rate is lower but requires more invasive procedures that may result in significant functional impairment.

Shock wave therapy

Shock wave therapy was initially proposed as a high-energy intervention to fragment the newly formed bone, based on the previously dominant mechanical action theory. Later, the rationale for its use was significantly reinterpreted, shifting to lower energy levels (while still penetrating deeply into the affected tissues) in alignment with the evolving understanding of the biological and regulatory effects of shock waves on inflammatory processes underlying ossification.

Therapy has been shown to be more effective when administered during the early phase of pathological progression. With early diagnosis and treatment, it is possible to reduce pain symptoms, improve joint mobility, and slow the growth of ossification, as described by Fiani (2020) and Kim (2022).

The likelihood of success is inversely proportional to the delay between the onset of functional limitation and the execution of therapy. The longer the interval and the more advanced the ossification process, the lower the chances of success, as measured by restored joint mobility. If performed after ossification stabilization, the results are significantly less effective.

Operational procedures

Shock wave therapy is typically administered using focused shock waves in a single session, preferably with devices that allow ultrasound and/or radiographic targeting (fig. 4). Sedation is generally not required.

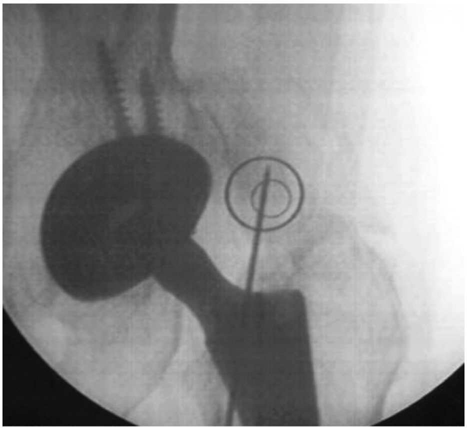

Figure 4 Radiographic targeting for shock wave therapy

Medium-to-high energy levels (between 0.18 and 0.24 mJ/mm^2) are used, with the number of pulses proportional to the size of the treatment area and the focal dimensions of the generator used (electrohydraulic generators: 1,500-2,000 pulses; electromagnetic generators: 2,500-3,500 pulses; piezoelectric generators: 4,000-5,000 pulses). The treatment target is the central area free of calcifications located between the ends of the ossification bridge that is forming.

After the treatment and follow-up

Immediately after shock wave therapy, the patient should undergo passive mobilization, including forced mobilization, if necessary, followed by a planned rehabilitation program aimed at restoring mobility and joint function, primarily through passive exercises.

Patients treated with shock wave therapy are monitored at 1 and 3 months post-treatment to assess pain symptoms and joint mobility.

X-ray evaluations proposed to assess the progression of ossification do not provide significant information before 6 months after shock wave therapy, as changes in the ossification process occur slowly and are not markedly evident in the initial months.

If necessary, shock wave therapy can be repeated after 1-3 months. The patient should continue to be monitored until ossification is fully stabilized.

What patients should know

The patient's cooperation in monitoring clinical signs and managing the mobilization of the joint segment is crucial; this activity must be consistent and regular. Imaging evaluations are not particularly indicative of the progression of the process, except in a negative sense. However, constant vigilance is essential, as the ossification process, after a silent phase, can resume its negative progression.

Differential diagnosis

Numerous conditions can cause discomfort in the lateral thigh compartment. This issue has been referred to as the “great mimicker” because some of its clinical features can mimic those of other conditions. These conditions, while originating from issues distant from the greater trochanter, can result in referred pain to the same anatomical area. In particular, intra-articular and extra-articular causes, as well as conditions causing referred pain, should be considered.

Intra-articular causes

- Hip osteoarthritis and cartilage damage.
- Acetabular labral tears.
- Femoroacetabular impingement.
- Capsular laxity.
- Ligamentum teres injuries.
- Stress fractures of the femoral neck.
- Avascular necrosis of the femoral head.

Extra-articular causes

- Greater trochanteric bursitis.
- Piriformis syndrome.
- Iliopsoas tendinitis.
- Snapping hip syndrome.
- Iliotibial band laxity.
- Gluteal insertional injuries.

Conditions causing referred pain

- Lumbosacral conditions (lumbosciatica with radiculopathy, lumbar stenosis, facet joint syndrome, lumbar spondylolisthesis, and sacroiliac joint dysfunctions of rheumatologic or mechanical origin).
- Fibromyalgia.
- Meralgia paresthetica.
- Complex regional pain syndrome.

Treatment

The initial therapeutic approach consists of conservative treatment, including functional rest, ice application, and the use of NSAIDs. However, the response to pharmacological treatment is often limited and rarely results in significant pain control, as the condition is more degenerative than inflammatory in nature. Attention should also be paid to addressing issues of overweight or obesity.

Physical therapies, such as laser therapy and ultrasound, may be employed, though the actual effectiveness of this approach has been evaluated in literature only when combined with other types of therapy. There is no conclusive evidence supporting their standalone efficacy.

Their findings highlighted greater effectiveness of shock wave therapy in the medium and short term.
In 2019, Carlisi et al. published a randomized controlled study comparing shock wave therapy to ultrasound therapy, demonstrating the superiority of shock wave therapy in managing pain in both the short and medium term. The following year, Ramon et al. conducted a multicenter randomized study comparing shock wave therapy to sham therapy. They found that shock wave therapy combined with specific rehabilitation programs was more effective than exercise alone, even in the long term.
In a recent review conducted by Korakakis and colleagues, it was highlighted that there is low-level evidence suggesting that shock wave therapy is less effective than corticosteroid injections in the short term but shows better results in the medium and long term. However, the authors emphasize that the studies considered contain methodological errors and varying diagnostic criteria for defining lateral hip pain, which justifies the low level of evidence for their findings.
Shock wave therapy is commonly used in cases of trochanteritis since, when performed without specific execution issues and combined with targeted rehabilitation exercises, it yields positive outcomes in alleviating pain and restoring functional gait. This allows patients to quickly regain the ability to engage in specific sports activities.
For contraindications related to shock wave therapy for trochanteritis, we refer to the SITOD Consensus Document: Indications, Contraindications, and General Recommendations (2019).

Operational protocol

The protocol typically follows these guidelines:

- a cycle of three sessions, scheduled weekly or biweekly;
- use of medium energy, with an energy flux density typically between 0.10-0.20 mJ/mm^2;
- a frequency of 4-6 Hz;
- the number of shocks depends on the type of generator used, ranging from 700 to 2000 shocks per session;
- there is no indication for the use of local anesthesia.

Based on literature review, no particular treatment protocol appears significantly more effective, provided the same energy level is applied. This includes variations in the number of sessions, their timing, or the energy levels used by different focused shock wave generators available on the market.
General recommendations include:

- the number of sessions should not be excessive, typically between two and four;
- the chosen energy level should be medium, not less than 0.10 mJ/mm^2;
- the total energy delivered should not be less than 3,000 mJ;
- anesthesia does not appear necessary.

Patellar tendinopathy

Maria Chiara Vulpiani, Mario Vetrano, Flavia Santoboni, Sveva Maria Nusca

Definition

Patellar tendinopathy (jumper's knee) is a chronic condition characterized by pain and functional limitation affecting the tendinous structures of the knee extensor apparatus. In most cases, it involves the proximal insertion of the patellar tendon at the inferior pole of the patella and, less commonly, the insertion of the quadriceps tendon at the superior pole of the patella (quadriceps tendinopathy) or the tibial insertion of the patellar tendon.

Epidemiology

Patellar tendinopathy is a common condition among athletes involved in jumping sports, typically occurring from adolescence to the fourth decade of life. It can lead to limitations in athletic performance and, in some cases, premature termination of a professional sports career.

The highest prevalence of this condition has been observed in volleyball players (approximately 14.5%) and soccer players (2.5%), particularly among elite athletes. Furthermore, imaging studies have identified signs of tendinopathy in 22% of asymptomatic athletes evaluated, with higher prevalence among males and basketball players. In basketball, a high prevalence has also been reported in youth athletes, both in the symptomatic form (7%) and the asymptomatic form (26%).

By contrast, patellar tendon rupture is less frequent and occurs mainly in older individuals, with an average age of 65 years, typically with pre-existing tendinopathy.

Etiopathogenesis

The underlying mechanisms of patellar tendinopathy and its associated symptoms remain poorly understood and are the subject of ongoing debate.

In addition to functional overload – potentially exacerbated by extrinsic factors such as training on hard surfaces, improper training methods, or inadequate equipment – intrinsic factors may also play a role. These include age, sex, body type, individual load response, or the presence of postural defects or foot abnormalities. However, no statistically significant association between these factors and the onset of the condition has been conclusively demonstrated.

It is generally believed that functional overload, in the presence of not entirely defined intrinsic factors, can lead to tendinopathy. As with other chronic tendinopathies, several etiopathogenetic models have been proposed for patellar tendinopathy, such as the mechanical model and the continuum model. The continuum model suggests a gradual progression through three stages (reactive, disrepair, and degenerative) under conditions of excessive load and predisposing factors.

The origin of tendon pain is difficult to interpret and may occur even in tendons that appear normal on imaging studies. However, tendon overload is currently such as VEGF, TGF-beta, and nitric oxide, which play a critical role in hypoxic or ischemic tissues.

It has been demonstrated that the development of nitric oxide (NO) plays a critical role in improving blood flow at the site of a chronic ulcer immediately after treatment with shock waves, accompanied by a reduction in local tissue inflammation. The increased perfusion in ischemic tissue is believed to result from the enhanced production of NO through both non-enzymatic and enzymatic mechanisms linked to the upregulation of nitric oxide synthase (NOS). According to research, nitric oxide plays a significant role in modulating various processes of angiogenesis. The early NO-mediated increase in perfusion is accompanied by neo angiogenesis in the ischemic tissue, along with the proliferative expression of nuclear cell antigens.

Shock waves strongly induce cascades of tissue regrowth, particularly the activation of TGF-beta1 and type 1 and 3 collagen, which are key factors involved in connective tissue repair processes. This highlights the beneficial role of shock waves in skin regeneration. Furthermore, shock waves stimulate the proliferation and recruitment of fibroblasts while enhancing extracellular matrix metabolism.

In summary, these effects appear to be linked to the increased release of both endogenous angiogenic factors from endothelial cells and fibroblasts, as well as local growth factors. They also involve the recruitment of appropriate stem cells to the target area, accompanied by stimulated revascularization. Additionally, it has been shown that the application of shock waves can improve lymphatic drainage in a chronic ulcer and in the treatment of stage 3 lymphedema triggered by breast cancer surgery.

It has therefore been demonstrated that extracorporeal shock waves can promote wound closure and complete epithelialization. Furthermore, the success of shock wave therapy appears to be independent of comorbidities.

Operating protocols

The application of the therapy is performed using a defocused applicator with characteristics similar to a focused shock wave generator. Our experience pertains to the use of an electrohydraulic generator, consisting of an ellipsoid filled with water. Inside this ellipsoid is a primary focal point (F1) formed by two electrodes placed 1 mm apart. The high voltage generated between these two electrodes creates a vapor bubble that expands within the ellipsoid, producing a pressure wave with the characteristics of a shock wave. This wave is reflected by the inner walls of the ellipsoid to an external point called F2, which represents the treatment area. Electrohydraulic technology generates a strong potential difference, producing a spark that creates a gas bubble. This bubble expands extremely rapidly in a spherical manner, resulting in a highly specific focal point. Since there is no membrane to move and no inertia to overcome, this technology allows for faster and more manageable focusing. Additionally, there is less delay between generating consecutive shock waves of the same type and power.

The defocused applicator allows the focal point to be directed far from the source, producing a quasi-parallel shock wave beam that creates a much larger treatment

Table I Differentiation of scars

Immature scar	The scar, during the remodeling process, appears red, sometimes itchy or painful, and slightly raised. Many of these will normally mature over time, becoming flat and taking on pigmentation similar to the surrounding skin, either lighter or slightly darker
Linear hypertrophic scar (e.g., surgical/traumatic)	Red, raised scar, sometimes itchy, confined to the edges of the original surgical incision. This type of scar typically appears within weeks after surgery. These scars can grow in size rapidly over 3-6 months and then, after a static phase, begin to regress. They generally have a slightly raised, cord-like appearance with variable dimensions. The complete maturation process can take up to 2 years
Diffuse hypertrophic scar (e.g., burn)	Red, diffuse, raised scar, sometimes itchy, that remains within the boundaries of the burn
Minor keloid	Focally raised scar, itchy, extending onto normal tissue. It may progress for up to 1 year after the injury and does not regress on its own. Simple surgical excision is often followed by recurrence. There may be a genetic abnormality involved in keloid scars. Typical sites include the earlobes
Major keloid	Large raised scar (> 0.5 cm), sometimes painful or itchy, extending onto normal tissue. Often secondary to minor trauma, it may continue to spread over the years

Table II Vancouver Scar Scale for the evaluation of clinical characteristics of scar abnormalities
Source: The Vancouver Scar Scale by Thompson CM et al. Burns. 2015 Nov; 41(7): 1442-1448

Pigmentation (0-2)		**Vascularity (0-3)**		**Pliability (0-5)**		**Height (0-3)**	
Normal	0	Normal	0	Normal	0	Normal (flat)	0
Hypopigmentation	1	Pink	1	Supple	1	0-2 mm	1
Hyperpigmentation	2	Red	2	Yielding	2	2-5 mm	2
		Purple	3	Firm	3	>5 mm	3
				Banding	4		
				Contracture	5		