Review Article

Extracorporeal shockwave therapy in managing lower urinary tract dysfunction: a scoping review

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ABSTRACT

Extracorporeal shockwave therapy (ESWT) exerts a range of biological effects, including anti-inflammatory, immunomodulatory, angiogenic, proliferative, and differential responses, as well as promoting nerve regeneration, enhancing membrane permeability, inducing stem cell attraction, and triggering the release of exosomes. It facilitates both interstitial and extracellular responses that support tissue regeneration by transferring energy into tissues. It may also reduce pain through hyperstimulation analgesia and attenuate inflammatory responses, making it a promising non invasive approach for various lower urinary tract dysfunction (LUTD) conditions, such as underactive bladder, overactive bladder, chronic pelvic pain syndrome, stress urinary incontinence, and interstitial cystitis. This study aimed to explore the efficacy and mechanisms of ESWT in managing LUTD.

KEYWORDS extracorporeal shockwave therapy, neurogenic bladder, urologic diseases

Lower urinary tract dysfunction (LUTD) encompasses various conditions, including urine storage problems to voiding difficulties.[1] Globally, the prevalence of LUTD varies by age, sex, and condition, with overactive bladder (OAB) affecting 11–16% of adults and underactive bladder (UAB) estimated to affect 12% of elderly adults.[2–4] LUTD is classified into neurogenic and non-neurogenic based on the underlying causes. Common neurogenic causes include spinal cord injury, spina bifida, multiple sclerosis, and Parkinson's disease.[5] Furthermore, LUTD can be categorized by the anatomic location of the problem in the lower urinary tract. Treatment options include behavioral therapy, medications, physical modalities, and invasive surgical procedures.[1]

Extracorporeal shockwave therapy (ESWT) is increasingly recognized as a non invasive therapy in regenerative medicine.[6] This procedure was initially developed in the 1980s to treat kidney or ureteral stones,[6] and is now widely used in orthopedics,[7]

neurology,[8] urology,[9] and dermatology.[10] ESWT uses rapid, high-energy acoustic waves that propagate through tissues, inducing interstitial and extracellular responses while promoting tissue repair and regeneration. Research suggests that ESWT may also reduce pain through hyperstimulatory analgesia and mitigate inflammatory responses, making it a potentially valuable approach to treat LUTD.[11]

The number of studies on the effectiveness and safety of ESWT in urology has increased in recent years. Low-energy extracorporeal shockwave (LESW) treatment has been employed as a therapeutic approach for LUTD disorders, such as chronic prostatitis, interstitial cystitis (IC), OAB, stress urinary incontinence (SUI), and erectile dysfunction, as it promotes anti-inflammatory effects, angiogenesis, and tissue regeneration.[9] Moreover, LESW has been proposed to enhance tissue permeability and facilitate intravesical delivery of botulinum toxin in OAB treatment in both animal[12] and human studies.[13] In rehabilitation settings, ESWT is widely accepted as an effective and safe non invasive modality, particularly when conservative or other non invasive treatments fail.[14] Despite the ability of ESWT to treat various diseases, including LUTD, there are several proposed underlying mechanisms for how shockwaves may function. This study aimed to comprehensively summarize the current understanding of the efficacy and mechanisms of ESWT in managing LUTD, evaluate its potential, and identify research gaps to guide future clinical studies.

Characteristics of ESWT

Shockwaves are acoustic biphasic supersonic waves that can restore body function by transferring energy into the human body. Compared with ultrasound waves, shockwaves have a thousand times greater pressure amplitude. Upon generation, a shockwave produces an intense high-pressure wave around 100 megapascals (MPa) lasting 10 nanoseconds, quickly followed by a negative pressure of approximately 10 MPa that persists for a few microseconds.[15] This distinct biophysical mechanism allows ESWT to influence various cellular and tissue functions, making it a valuable therapeutic tool for multiple medical applications, including LUTD.[16]

Types of ESWT

Shockwaves are categorized into different types based on various criteria. Generators employed for wave production are classified as electrohydraulic, electromagnetic, or piezoelectric. Based on the source and design, shockwaves are divided into focused, defocused, planar, and radial, with the first three being referred to as ESWT.[15] Radial shockwaves produced by compressed air devices differ in their characteristics from those of other acoustic shockwaves. Shockwave therapy is further classified by wave propagation modality into focused shockwave therapy (FSWT) and radial shockwave therapy (RSWT). FSWT uses water to create focused shockwaves, whereas RSWT is generated by accelerating a projectile.[6] The distinctions between the two varieties are presented in Table 1, as described in a previous study by Simplicio et al.[6]

Mechanisms of ESWT

ESWT affects human tissues in four phases: physical, physicochemical, chemical, and biological. In the initial physical phase, shockwaves cause energy absorption, reflection, refraction, and transmission to tissues and cells via positive pressure. In the physicochemical phase, a physical stimulus initiates a biochemical reaction. During the chemical phase, shockwaves modify ion channel activity in cell membranes and facilitate calcium mobilization. Finally, the biological phase comprises the modulation of angiogenesis and inflammation, which support bone and soft tissue healing.[6]

Although these phases explain the effects of ESWT, the precise molecular mechanisms remain poorly understood, especially with regard to LUTD treatment. The variability in study outcomes reflects this knowledge gap and emphasizes the need for further research on how ESWT interacts with specific bladder and urinary structures. Additionally, the lack of standardized dosing protocols, with discrepancies in high-, medium-, and low-energy classifications, remains an issue.[16]

Dosage of ESWT

The energy transmitted by a shockwave per square area (mJ/mm^2) is known as the energy flux density (EFD). There is no international consensus on the cutoff values for high-, medium-, and low-energy shockwaves. However, Rompe et al[17] proposed classifying ESWT into high (>0.6 mJ/mm^2), medium (0.08–0.28 mJ/mm^2), and low (>0.08 mJ/mm^2) energy levels to explain dose-related effects of ESWT on animal models. In addition, ESWT has been reported to have significant

Table 1. Differences between FSWT and RSWT

Physical characteristics	FSWT	RSWT
Wave propagation	Focused	Radial
Pressure	Up to 100 MPa	0.1 to 1 MPa
Duration of pulse	≤2 µs	1 to 5 ms
Power of penetration	10–12 cm	<3 cm
Force of impact	0.001–0.4 mJ/mm (EFD >0.1 mJ/mm^2 (low); EFD of 0.2 to 0.4 mJ/mm^2	0.02–0.06 mJ/mm^2
Energy profile	Pressure waves rise and fall rapidly	Pressure waves rise and fall slowly
Target	Skin, muscles, and bone	Skin and muscles

EFD=energy flux density; FSWT=focused shockwave therapy; RSWT=radial shockwave therapy
The differences are based on Simplicio CL, Purita J, Murrell W, Santos GS, Dos Santos RG, Lana JF. Extracorporeal shock wave therapy mechanisms in musculoskeletal regenerative medicine. J Clin Orthop Trauma. 2020;11(Suppl 3):S309–18

biological effects on tendons, including enhanced neovascularization, cellular changes, and modifications of the extracellular matrix.[18] A review article discussing the impact of ESWT on soft tissue issues proposed that EFD ≤0.12 mJ/mm^2 be classified as low-energy ESWT and EFD >0.12 mJ/mm^2 as high-energy ESWT.[15] Bannuru et al[19] considered EFD ≥0.28 mJ/mm^2 as high-energy ESWT and EFD <0.28 mJ/mm^2 as low-energy. Similarly, Wang et al[9] characterized low-intensity ESWT (Li-ESWT) as having an EFD of <0.2 mJ/mm^2.

EFD is a pivotal factor in the therapeutic use of ESWT; however, the specific indications and contraindications for each energy level remain complex and lack standardization. High-energy ESWT (0.6 mJ/mm^2) is indicated for conditions requiring deep tissue penetration and robust biological effects, such as chronic musculoskeletal injuries or severe tendinopathies, where other treatments have failed.[6] However, high-intensity shockwave therapy is unsuitable for patients with acute inflammation, recent injuries, or those at higher risk of complications, such as individuals on anticoagulants or with bleeding disorders, as it could exacerbate inflammation or negatively impact sensitive structures.[20]

Medium-dose ESWT (0.08–0.28 mJ/mm^2) is typically applied in moderate chronic pain cases, such as plantar fasciitis and tendinopathy, or in urological conditions like OAB, as it provides targeted tissue regeneration with less extensive penetration than high-energy ESWT. However, the application of medium-dose ESWT requires caution near sensitive areas, especially in the urogenital region, and it should not be used on acute injuries or unhealed fractures.[19] Meanwhile, low-energy ESWT (≤0.08 mJ/mm^2) is primarily used for early-stage or mild conditions like mild chronic tendinopathy or initial OAB therapy, respectively. Low-energy ESWT stimulates mild anti-inflammatory responses and promotes angiogenesis and nerve stimulation, making it suitable for treating superficial soft tissue issues. Despite fewer contraindications, low-energy ESWT may be less effective for advanced or treatment-resistant conditions but is contraindicated in patients with shockwave sensitivity or recent injuries that require a more conservative approach.[21]

The key differences between low- and medium-dose ESWT are the penetration depth and the degree of biological effects elicited.[16] Low-energy ESWT promotes mild angiogenesis and cellular activity, suitable for superficial or early-stage conditions. Medium-dose ESWT reaches deeper tissue structures and generates stronger anti-inflammatory responses and tissue remodeling effects that are beneficial for moderate conditions, such as OAB or IC. Standardizing EFD thresholds in clinical protocols could improve therapeutic outcomes and guide dosage selection for ESWT applications under various conditions.[16]

Biological effects of ESWT

ESWT induces various biological effects that contribute to tissue repair and regeneration. Previous research has documented several key mechanisms that enhance blood flow and tissue healing, including anti-inflammatory responses, immunoregulation, and neovascularization.[6,22,23] In addition, ESWT promotes cell proliferation and differentiation, facilitates stem cell attraction, and stimulates exosome release, all of which play essential roles in cellular communication and regeneration. Furthermore, ESWT has been linked

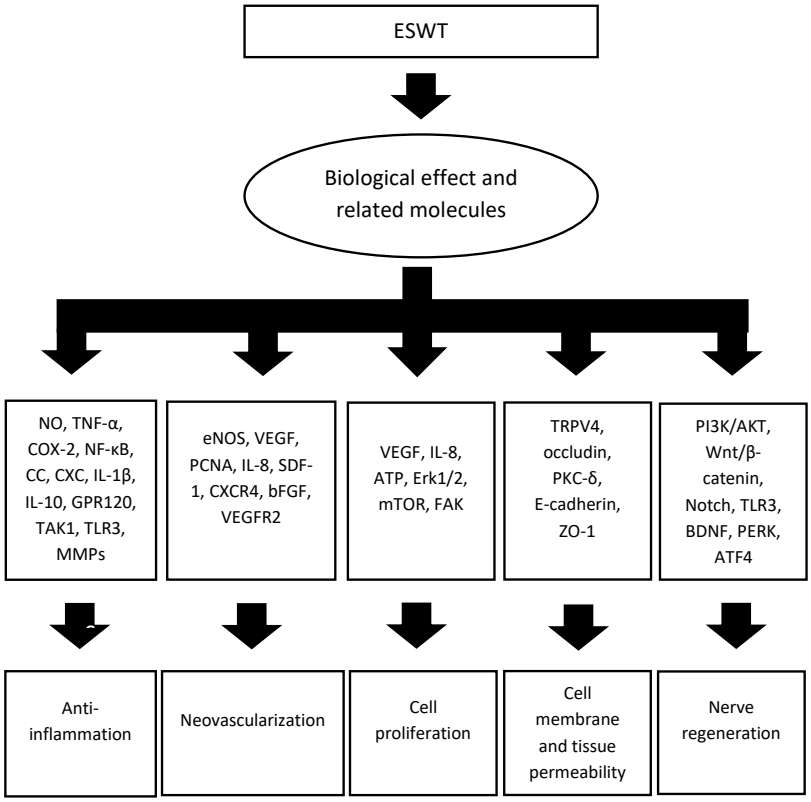

Figure 1. Suggested biological effects of ESWT. ATF4=activating transcription factor 4; ATP=adenosine triphosphate; BDNF=brain-derived neurothropic factor; bFGF=basic fibroblast growth factor; CC=adjacent cysteine location; COX-2=cyclooxygenase-2; CXCR4=C-X-C motif chemokine 4; CXC=separation by a non-conserved amino acid; eNOS=endothelial nitric oxide synthase; Erk1/2=extracellular signal-regulated kinase 1/2; ESWT=extracorporeal shockwave therapy; FAK=focal adhesion kinase; GPR120=G-protein coupled receptor 120; IL=interleukin; MMPs=matrix metalloproteinases; mTOR=mammalian target of rapamycin; NF-κB=nuclear factor kappa B; NO=nitric oxide; PCNA=proliferating cell nuclear antigen; PERK=protein kinase R-like endoplasmic reticulum kinase; PI3K/AKT=phosphoinositide 3-kinase/protein kinase B; PKC-δ=protein kinase C delta; SDF-1=stromal cell-derived factor 1; TAK1=transforming growth factor beta-activated kinase 1; TLR3=toll-like receptor 3; TNF-α=tumor necrosis factor alpha; TRPV4=transient receptor potential cation channel, subfamily V, member 4; VEGF=vascular endothelial growth factor; VEGFR2=vascular endothelial growth factor receptor 2; Wnt/β-catenin=Wnt/β-catenin signaling pathway; ZO-1=zonula occludens-1. Adapted from: Chen PY, Cheng JH, Wu ZS, Chuang YC. New frontiers of extracorporeal shock wave medicine in urology from bench to clinical studies. Biomedicines. 2022;10(3):675 under the Creative Commons Attribution license (CC BY 4.0) https://creativecommons.org/licenses/by/4.0/

to neural regeneration and increased cell membrane permeability, which further supports its therapeutic potential in various medical applications (Figure 1).[15] Studies have suggested that different EFD levels elicit distinct biological responses, influencing critical processes such as cellular regeneration, angiogenesis, and inflammation. Higher or lower EFD values may result in different therapeutic outcomes, therefore, understanding the dose-dependent effects of ESWT is crucial for maximizing efficacy and ensuring safe and effective treatment strategies.[24]

Anti-inflammation

ESWT promotes the anti-inflammatory process by reducing the expression of tumor necrosis factor alpha, cyclooxygenase-2 (COX-2), chemokines (adjacent cysteine location[6] and separation by a non-conserved amino acid [CXC] types), and nuclear factor kappa B (NF-κB).[22] In animal models, ESWT also induces the release of G-protein coupled receptor 120, which hinders the expression/activity of transforming growth factor beta-activated kinase 1 and regulates NF-κB signaling in the inflammatory response.[22] Sukubo et al[25] showed that low-energy shockwaves inhibit the development of a pro-inflammatory profile while fostering an anti-inflammatory environment in M1 macrophages and are associated with significant changes in interleukin (IL) expression/activity. Research has suggested that low-energy ESWT (≤0.08 mJ/mm^2) primarily relays superficial anti-inflammatory

effects, suitable for conditions requiring minimal tissue penetration, while medium- and high-energy ESWTs exert stronger anti-inflammatory responses suitable for deeper tissue conditions.[23] Additionally, ESWT alters inflammation through the toll-like receptor 3 (TLR3) pathway, which includes the effector molecules IL-6 and IL-10.[26,27] Furthermore, ESWT inhibits pro-inflammatory cytokines, matrix metalloproteinases, and chemokines, and attenuates leukocyte infiltration in animal models of wounds, severe skin burns, and cystitis.[15,27–29]

Angiogenesis

Wang et al[30] examined the impact of ESWT on neovascularization in animal models and suggested that ESWT induces neovascularization through the enhanced expression of angiogenesis-related markers, such as endothelial nitric oxide synthase (eNOS) and vascular endothelial growth factor (VEGF), and expression of the proliferating cell nuclear antigen protein. Another study further confirmed that ESWT significantly promotes angiogenesis by activating cellular pathways associated with neovascularization.[23] ESWT stimulates nitric oxide production and upregulates angiogenic factors like VEGF, enhancing blood flow and capillary density in treated tissues. These effects improve tissue repair, particularly in ischemic and injured tissues, by enabling better oxygen and nutrient delivery.[31] Moreover, studies have demonstrated that several ESWT sessions significantly accelerated diabetic wound healing by increasing neovascularization and tissue regeneration.[32] ESWT increased the expression of angiogenic factors, such as VEGF, IL-8, eNOS, stromal cell-derived factor 1, basic fibroblast growth factor, and C-X-C motif chemokine 4, resulting in improved tissue perfusion in both animal studies and clinical trials.[15] Huang et al[33] argued that ESWT promotes neovascularization by activating specific receptors of VEGF and extends this effect through endosome-to-plasma membrane recycling in human umbilical vein endothelial cells. Studies indicate that low-energy ESWT promotes initial angiogenesis at superficial levels, while medium- and high-energy ESWT elicit more significant vascular effects that support tissue regeneration in deeper and more complex structures.[34] This gradation of angiogenic responses based on EFD is essential for clinical applications in chronic wounds or deep tissue injuries requiring substantial tissue remodeling.

Cell proliferation

Cell proliferation is essential for tissue regeneration. ESWT promotes the expansion of endothelial progenitor cells (EPCs) and enhances cardiac performance in patients with resistant coronary artery disease by elevating VEGF and IL-8 levels.[35] Shockwave therapy enhances VEGF and IL-8 activity/expression, encouraging the growth of EPCs to support tissue repair and neovascularization.[36] Moreover, ESWT promotes *in vitro* and *in vivo* proliferation through extracellular signal-regulated kinase 1/2 pathway by inducing cellular ATP production and activating purinergic receptors.[37] Furthermore, ESWT has been proven to activate the focal adhesion kinase mechanotransduction signaling axis, thereby promoting mesenchymal stem cell proliferation.[38] Notably, low-energy ESWT can enhance surface-level cell proliferation, aiding soft tissue repair, while medium-dose ESWT facilitates more extensive proliferation, suitable for conditions needing greater tissue rebuilding, such as tendinopathy and urological conditions.[39] High-energy ESWT is particularly effective for resistant pathologies, where robust cellular responses are necessary for meaningful regeneration.[37]

Nerve regeneration

Hausner et al[40] showed that ESWT improves the axonal regeneration rate in animal models of sciatic nerve injury by fostering Wallerian degeneration, improving the removal of the degenerated axons, and regenerating injured axons. In a related study, ESWT was shown to support nerve repair by enhancing both structural and functional recovery in sciatic nerve injury models by clearing damaged axons and stimulating new axonal growth, helping to restore nerve function and reduce deficits.[41] Lee and Cho[42] demonstrated a notable increase in the sciatic functional index score, decreased muscle atrophy, reorganization of damaged nerves, and activation of muscle-neuron conjunction in animal models following ESWT. Studies have also suggested that ESWT induces tissue regeneration by regulating the inflammatory response through TLR3, resulting in neuroprotection and facilitating spinal cord repair in a mouse model of spinal cord contusion.[43] ESWT also promotes nerve regeneration by increasing brain-derived neurotrophic factor expression and activating the protein kinase R-like endoplasmic reticulum kinase/activating transcription factor 4 signaling pathways.[44] However, the detailed mechanism of how ESWT promotes nerve regeneration remains unclear and

requires further investigation. Low-energy ESWT has shown efficacy in the initial nerve healing processes, while medium- and high-energy ESWT have a more pronounced effect in regenerating complex neural structures.[45] This range of ESWT effects, based on EFD, highlights the potential for tailored treatment of nerve-related dysfunctional diseases, such as certain LUTD.

Utilization of ESWT in LUTD

ESWT has shown promise in the management of LUTD as it promotes tissue regeneration and modulates nerve activity. Previous studies have suggested that ESWT may be beneficial for conditions such as UAB,[46] OAB,[47] chronic pelvic pain syndrome (CPPS),[48] and IC[28] by enhancing neuromuscular function and relieving symptoms. Furthermore, ESWT has been explored as a potential therapy for patients with urinary incontinence,[15] as it may strengthen the pelvic floor muscles. While research is still ongoing, ESWT offers a promising alternative for patients seeking nonsurgical treatment options for LUTD.

UAB

Previous studies have demonstrated the potential of ESWT in the management of UAB. LESW has demonstrated potential in the treatment of UAB, highlighted by its promotion of tissue regeneration and functional recovery. Typically, LESW is administered using EFD levels of ≤0.08 mJ/mm^2, with a shallow probe depth to specifically target the bladder wall. This approach aims to enhance bladder wall composition, facilitate muscle regeneration, and improve neural innervation, all of which are essential for restoring normal bladder function.[49] Standard treatment protocols often consist of weekly sessions conducted over a period of 4 to 8 weeks, allowing for gradual but measurable improvements in urinary function. Clinical observations suggest that patients frequently experience positive therapeutic effects within this timeframe, highlighting LESW as a promising noninvasive intervention for UAB management.[47]

In a diabetes-induced UAB mouse model, ESWT significantly improved bladder function and structure by enhancing the bladder wall composition, stimulating the regeneration of bladder muscles, and increasing the contractile function of both the bladder and urethra.[50] Additionally, therapy improves neural innervation and supports urethral continence, improving overall urinary control. Furthermore, an *in vitro* study investigating the effects of LESW in a cryoinjury-induced UAB rat model found a reduction in the expression of the pro-inflammatory markers IL-6 and COX-2. These findings suggest that ESWT and LESW have therapeutic potential for mitigating inflammation and enhancing functional recovery in UAB, particularly in cases associated with diabetes or tissue injury.[51]

OAB

A study by Lee et al[52] on females aged 20–75 years with OAB suggested that Li-ESWT can significantly increase functional bladder capacity after 8 weeks of treatment. The treatment used Li-SEWT with intensity of 0.25 ml/mm^2, 3,000 pulses and three pulses/sec at a frequency of once per week for 8 weeks, using a probe that was placed on the suprapubic skin area. A notable increase in the average voided volume following the application of Li-ESWT was also observed in this study.

Similarly, Lu et al[53] demonstrated improvement in OAB symptoms, heightened voiding efficacy, and better quality of life (QoL) among women aged 20–75 years who did not use antimuscarinic agents or β3 agonists after 8 weeks of Li-ESWT. Lin et al[54] demonstrated significantly improved bladder storage function after Li-ESWT in ovariectomized animal models. For treatment of OAB, ESWT is typically administered with an EFD <0.12 mJ/mm^2, at a frequency of 2,000–3,000 pulses per session, once weekly for 8–12 weeks. The probe depth used is moderate, ensuring sufficient tissue penetration to improve bladder function. Current evidence supports the effectiveness of ESWT in managing OAB, although further research or evidence-based clinical studies would strengthen its clinical applicability.

CPPS

Previous research supports the effectiveness and safety of Li-ESWT in the management of various urogenital disorders, including CPPS. Wu et al[48] found that ESWT improved QoL and sexual function in patients with non-inflammatory chronic prostatitis/CPPS, with benefits lasting for up to 12 months. They argued that this improvement was attributable to intracellular changes caused by the conversion of mechanical shockwaves from ESWT into biological signals. Another possibility is that ESWT may eliminate the connection between the input of sensory pain and the output of motor nerve signals via synaptic plasticity mechanisms, resulting in reversed pain perception.

ESWT also exhibits pain-relief potential by selectively eliminating pathological reflexes.[48]

Zhang et al[55] compared the impact of radial extracorporeal shockwaves therapy (rESWT) (3,000 pulses each; pressure: 1.8–2.0 bar; frequency: 10 Hz; once a week, for 8 weeks) with a drug regimen (α-blocker combined with an anti-inflammatory) to treat CPPS and type IIIB chronic prostatitis. The study was conducted on 45 participants that were divided into two groups: 25 participants receiving rESWT (group I) and 20 participants receiving a combination of α-blocker combined with an anti-inflammatory (group II). Both patient groups reported improved pain levels and QoL after 4 weeks of treatment, but an improvement in clinical score was more prominent in the intervention group after 8 weeks, suggesting that rESWT was more effective with increased treatment time. Moreover, the therapeutic effect of rESWT was longer than that of medications in this study. The improvement in patients with CPPS who received rESWT may be partially mediated by its antispasmodic effect.

In animal models, LESW can induce endogenous stem cell recruitment and Schwann cell activation, promoting angiogenesis, tissue formation, and nerve regeneration.[56] For CPPS, Li-ESWT uses an EFD of 0.1–0.2 mJ/mm^2 with weekly sessions of 3,000 pulses at 1.8–2.0 bar for 4–12 weeks. A moderate probe depth is selected to target deeper pelvic tissues, which is thought to contribute to significant pain relief and QoL improvement. This protocol aligns with Li-ESWT, and contraindications include untreated infections, recent surgeries, or proximity to major nerves.[54]

IC

Shen et al[46] conducted a study with 25 individuals aged 20 years and older diagnosed with IC who had experienced treatment failure for a minimum of 6 months with conventional therapies, such as non-steroidal anti-inflammatory drugs, intravesical hyaluronic acid instillation, hydrodistension, or intravesical botulinum toxin. The study aimed to evaluate the efficacy of ESWT in reducing clinical symptoms, as measured using the O'Leary-Sant symptom score (OSS), and alleviating pain, as evaluated using a visual analog scale (VAS). The intervention group received ESWT with 2,000 shocks, a frequency of three pulses/sec, and a maximum EFD of 0.25 mJ/mm^2 once a week for 4 weeks, and the outcomes were measured on the 4th and the 12th week. A significant decrease was observed in the OSS and VAS scores in the intervention group compared to the placebo group after 4 weeks, and effects persisted at the 12-week timepoint. This improvement was linked to changes in the levels of certain urine cytokines and chemokines, such as IL-4, IL-9, and VEGF.

Typically, ESWT for IC is administered using EFDs ranging from 0.12–0.25 mJ/mm^2, delivering approximately 2,000 pulses per session on a weekly basis. A moderate probe depth is employed to ensure effective penetration of shockwaves into the bladder wall to promote tissue healing and improve symptoms. Although this treatment regimen has shown promising results in alleviating IC-related discomfort, contraindications must be considered to ensure patient safety. Individuals with active bladder infections, recent surgical procedures, or bleeding disorders may be at a higher risk of complications, as ESWT could potentially exacerbate adverse effects in these conditions.[57]

SUI

SUI is characterized by unintentional urine leakage during physical activities such as exertion, coughing, or sneezing. A study on the effect of Li-ESWT included 60 women aged 20–75 years who had been diagnosed with SUI for more than 3 months. The participants underwent Li-ESWT therapy once a week for 8 weeks, with treatment parameters set at an intensity of 0.25 mJ/mm^2, 3,000 shock pulses, and three pulses/sec. After 4 weeks of therapy, 64.4% of the participants experienced moderate-to-substantial improvement (>50%), and this positive effect persisted for 6 months. No participant experienced side effects during treatment or follow-up.[54]

This review acknowledges the limitations of ESWT research, including selection bias and variability in study design and outcomes. Small sample sizes and the lack of large-scale clinical trials restrict the generalizability, particularly for LUTD-specific studies. Moreover, this review cannot justify the probe location for each LUTD condition, as such detailed information was not available in the reviewed literature. This may pose challenges in the clinical implementation of ESWT for LUTD management. Furthermore, the variability in ESWT dosing and methodology complicates direct comparisons between studies. Future research should prioritize randomized controlled trials with standardized and detailed protocols to establish robust and reproducible evidence to inform clinical guidelines.

In conclusion, the efficacy and safety of ESWT for LUTD have been attributed to its ability to induce diverse biological effects and support the restoration of bodily function. However, the specific mechanisms and molecular changes following ESWT are not fully understood, owing to the limited number of clinical studies in this area. Further research is required to understand these underlying mechanisms better.

Conflict of Interest

The authors affirm no conflict of interest in this study.

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