Extracorporeal Shockwave Therapy in Greater Trochanteric Pain Syndrome: A Systematic Review and Meta-Analysis

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Extracorporeal Shockwave Therapy in Greater Trochanteric Pain Syndrome: A Systematic Review and Meta-Analysis

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SUMMARY

Background. Greater Trochanteric Pain Syndrome (GTPS) poses significant challenges in clinical management due to its multifactorial etiology and limited treatment options. Extracorporeal Shockwave Therapy (ESWT) has emerged as a promising intervention in the recent past. This review aimed to evaluate the clinical efficacy of ESWT in managing GTPS symptoms.

Methods. Systematic searches were conducted on PubMed, Scopus, PEDro, and Web of Science. For quality assessment we utilized the PEDro scale, while Cochrane Risk-of-bias tool version 2 (RoB 2) helped evaluate the risk of bias. Meta-analysis was performed on six out of seven included studies. The primary outcome studied was pain intensity, and secondary outcome was lower extremity function. The analysis was done for r-ESWT and f-ESWT separately, wherever applicable.

Results. Seven trials with 714 participants were analyzed; six included in the meta-analysis. The meta-analysis of trials where f-ESWT was given showed that f-ESWT was significantly more effective than control/alternative treatments (SMD = -1.96; 95%CI -3.22 to -0.71; Z = 3.06, p = 0.002) in reducing pain, with significant results obtained in the medium, but not in the long term. f-ESWT was found to be more effective in improving lower extremity function in GTPS (SMD = 0.61; 95%CI 0.41 to 0.81; Z = 6.02 p < 0.00001). r-ESWT did not offer any significant benefit for reducing pain intensity over control/alternative treatments in either short, medium, or long-term follow-ups (SMD = -0.03; 95%CI -0.41 to 0.35; Z = 0.16, p = 0.87).

Conclusions. f-ESWT can improve pain intensity and lower extremity function more significantly when compared to control/alternative treatment groups.

Study registration. The procedure used for analysis and the pre-determined eligibility criteria was registered at the International Prospective Register of Systematic Reviews (PROSPERO) on March 04, 2024, registration ID: CRD42024515778.

KEY WORDS

ESWT; extracorporeal shockwave therapy; GTPS; lateral hip pain; shockwave.

INTRODUCTION

Greater Trochanteric Pain Syndrome (GTPS) is a clinical condition that manifests as chronic pain and tenderness around the greater trochanter, often extending to the lateral aspect of the hip or thigh and exacerbated by physical activity (1, 2). GTPS encompasses various disorders of the lateral hip region, including trochanteric bursitis, tears of the gluteus medius and minimus, and external coxa saltans (3), with gluteal tendinopathy considered a primary source of lateral hip pain (4). The incidence rate of GTPS is 1.8 patients per 1000 per year. Reportedly, GTPS affects women more than men, with the ratio being as high as 4:1 (5). Further, in primary care settings, the cause of hip pain in approximately 10-20% patients is

commonly attributed to trochanteric pain (6). In fact, with a prevalence of 4.22/1,000 person-years, GTPS is evidently more prevalent than plantar heel pain (7), yet long-term data on this ailment is scarce.

The diagnostic criteria for GTPS have evolved, moving beyond specific signs to a broader clinical presentation. The resisted external de-rotation test, resisted hip abduction, Patrick's or FABER test, and palpation of the greater trochanter were identified as exhibiting the highest diagnostic test accuracy for GTPS (8). Deep and aching pain which gets exacerbated with activities like stair-climbing, squatting, cross-legged sitting, *etc*., is characteristic to GTPS. Moreover, the high prevalence of GTPS coupled with the absence of established treatment protocols highlights the necessity for standardized diagnostic criteria to steer effective management strategies (9).

The intricate nature of hip biomechanics and the subsequent challenges in distinguishing between various diagnoses pose difficulties for clinicians in devising suitable treatment strategies. Nevertheless, conservative therapy remains the cornerstone of initial management. Conservative approaches for treating GTPS encompass corticosteroid injections, platelet-rich plasma injections, hyaluronic acid injections, dry needling, structured exercise programs, and extracorporeal shockwave therapy (10). However, when conservative approaches fail to alleviate symptoms, surgical options such as open or endoscopic procedures may be necessary (11). Surgical procedures like tendon release and reattachment or bursectomy can also be undertaken to address GTPS. The objective of these surgical interventions is to target the root causes of lateral hip pain and functional impairment (12).

Shock wave therapy presents a promising avenue for effectively managing GTPS. This is because ESWT is utilized to induce neovascularization at the interface between tendon and bone, facilitating the release of growth factors. This cascade of events subsequently promotes enhanced blood supply, heightened cellular proliferation, and ultimately, the regeneration of tendon and bone tissues, thereby facilitating tissue repair (13). ESWT employs acoustic waves to selectively target areas, which exhibit transient pressure oscillations that spread in three dimensions, typically resulting in a pronounced pressure surge within a brief span of nanoseconds (14). These pressure impulses rapidly ascend from 5 to 120 MPa within approximately 5 ns, succeeded by a decline to negative pressure levels of -20 MPa (15), stimulating tissue regeneration via mechanotransduction mechanisms. There are two primary categories of ESWT: focused shockwave therapy (f-ESWT) and radial shockwave therapy (r-ESWT). The f-ESWT beam is characterized by its concentrated shape, directing pressure to converge towards an adjustable focus at a specific depth within body tissues (16), while r-ESWT delivers maximum energy near the handpiece, with a radially-directed beam (17).

In an antecedent systematic review scrutinizing evidence across various lower-limb tendon afflictions (18), it was noted that ESWT could be a promising alternative to existing treatments of GTPS, including corticosteroid injections. However, the aforementioned review did not exclusively focus on GTPS, and since its publication, subsequent studies have also emerged. The existing literature is inconclusive and ambiguous about the effects, dosage, and benefits of ESWT for patients with GTPS, especially when the duration for which the effects can sustain is concerned. Therefore, this study aimed to review the literature on clinically significant effects of extracorporeal shockwave therapy on pain and function for patients suffering from Greater Trochanteric Pain Syndrome (GTPS) for a short and a long-term follow-up. We aim to compare the differential effects of focused and radial shockwave therapy on the above-mentioned outcomes in patients with GTPS.

MATERIALS AND METHODS

The guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) were adhered to in the current systematic review and meta-analysis.

Search strategy

Literature was searched from inception till March 2024 independently by the authors (A.D.A., A.G.) through electronic database searches using PubMed, Web of Science (WoS), Scopus, and PEDRo, databases. The medical subject headings/keywords were "extracorporeal shockwave therapy", "greater trochanteric pain syndrome", connected by Boolean operator logic ("AND" and "OR"). Search was limited to RCT's and randomized cross-over trials. Unique search strategies were formulated for each database- PubMed, Web of Science (WOS), Scopus, and PEDRo.

Eligibility criteria

To develop the targeted question for this study, the PICOS acronym was utilised. The structured PICOS format was detailed as follows:

- P (Population): Patients diagnosed with Greater Trochanteric Pain Syndrome (GTPS)

- I (Intervention): Extracorporeal shockwave therapy (ESWT)
- C (Comparison): Placebo-controlled, usual care, corticosteroid injections, dry needling, Platelet-Rich Plasma (PRP), physiotherapy/exercise therapy, or other non-surgical treatment.
- (Outcomes): Pain, lower extremity function, and treatment satisfaction.
- S (Study design): Randomized Controlled Trials and Randomized Cross-over Trials

Inclusion criteria

Randomized Controlled Trials and Randomized Cross-over Trials assessing the effects of ESWT on GTPS in humans were included. The language of the selected studies was limited to English. The included studies compared the effects of ESWT *versus* groups that received sham treatments or conservative interventions. We selected studies that enrolled patients who were diagnosed with GTPS, confirmed through instrumental examination (ultrasound and/or MRI) or meeting diagnostic criteria for GTPS. Studies including subjects who were at least 18 years old and had positive findings on physical examination such as pain localized to the greater trochanteric area, local tenderness on palpation, pain with resisted external rotation or hip abduction were selected. No restrictions on severity of symptoms, energy intensity, treatment period, type of ESWT, etc., were considered during study selection.

Exclusion criteria

The criteria for exclusion were non-randomized studies, animal studies, the availability of only conference papers or abstracts, and studies with subjects with a history of hip osteoarthritis or knee osteoarthritis, previous fractures, hip surgery, or spinal surgery, total hip arthroplasty, acute trauma, systemic, inflammatory, or infective diseases, neurological diseases, neoplasm, etc.

Data extraction

Two reviewers (A.D.A., A.G.) conducted independent screening of titles and abstracts based on predefined inclusion and exclusion criteria, followed by a comprehensive examination of relevant literature in full text. Studies meeting the predetermined criteria were incorporated. In instances of disagreement, a third reviewer (C.S.) was consulted for assessment assistance. The reviewers autonomously extracted data including outcome indices, measurement timing, available follow-up duration, intervention particulars, publication year, first author, and sample size. Flow of the study selection process is illustrated in **figure 1**.

Methodological quality assessment

The methodological quality of the RCTs (n = 6) included was evaluated using the Physiotherapy Evidence Database scale (PEDro), known for its high reliability and validity. Two reviewers, (A.D.A. and A.G.), independently assessed the studies, and any inconsistencies were resolved through deliberation with a third reviewer (S.S.). The methodological quality of the included studies was evaluated based on 11 criteria, which included aspects such as eligibility criteria, randomized allocation, blinding, follow-up, and analysis methods. Each criterion was assigned a point when met, except for criterion number 1, which wasn't factored into the total score calculation. Thus, the total score ranged from 0 to 10, representing the number of criteria fulfilled by each study. Study quality was categorized

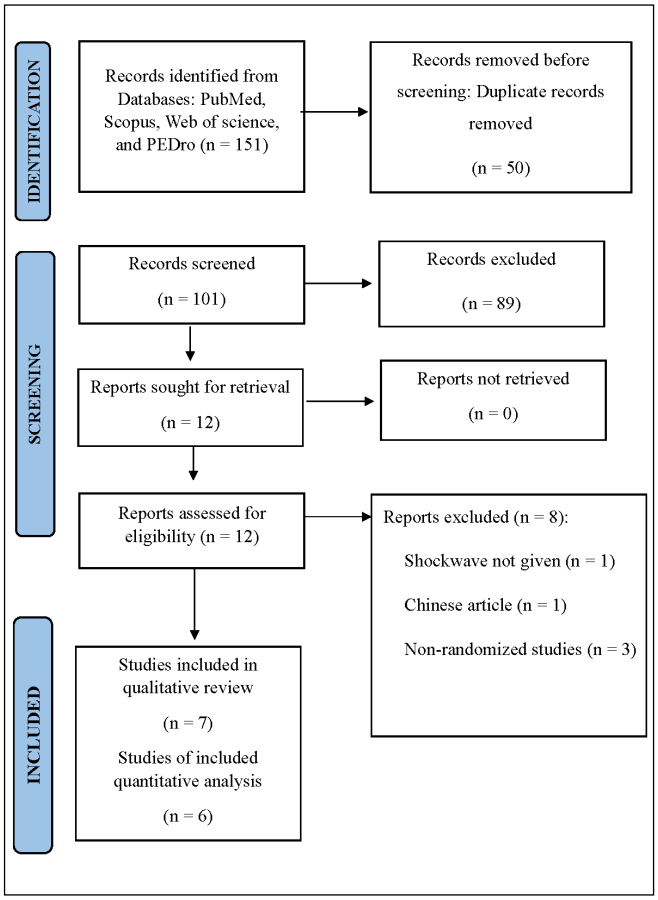

Figure 1. Prisma Flow Diagram.

A graphical representation of search strategy, retrieval of articles, exclusion, inclusion, and evidence synthesis.

Table I. Methodological Quality Assessment.

Author	Eligibility criteria	Random allocation	Concealed allocation	Baseline comparability	Blind subjects	Blind therapists	Blind assessors	Follow-up dropout <15%	Intention-to-treat analysis	Between group comparisons	Point estimate and variability	Score (/10)
Carlisi *et al.*, 2018	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Heaver *et al.*, 2021	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	6
Ramon *et al.*, 2020	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	8
Rompe *et al.*, 2009	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	6
Wheeler *et al.*, 2022	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	9
Yagchi *et al.*, 2023	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	7

as poor (PEDro score < 4), fair (PEDro score 4-5), good (PEDro score 6-8), and excellent (PEDro score 9-10) (19). Additionally, this scale demonstrated satisfactory reliability, with an intra-class correlation coefficient of 0.68 (20) (**table I**).

Assessment of risk of bias in studies

The Cochrane Risk of Bias Tool version 2 (RoB 2) was employed to evaluate the risk of bias within the studies analyzed. RoB 2 is organized into specific domains of bias, each targeting various aspects of trial setup, execution, and documentation. These domains consist of a predetermined set of questions, known as 'signalling questions', designed to gather pertinent details about the trial's methodology, providing valuable insights to readers regarding the rigor maintained by the investigators. All studies were scrutinized across various domains, such as randomization processes, timing of participant recruitment identification, deviations from intended interventions, absence of outcome data, outcome measurement, selection of reporting outcome, and overall bias. Each domain was then categorized as low risk, unclear, or high risk. For consistency, two researchers (A.D.A. and A.G.) independently evaluated the studies using the RoB 2.0 tool. Any discrepancies were resolved through deliberation with a third reviewer (C.S.), ultimately reaching a final assessment through consensus.

Quantitative synthesis

The findings from studies with similar clinical and statistical characteristics were combined through meta-analysis utilizing the Review Manager (RevMan) software version 5.4. The quantitative analysis was performed separately for focused and radial shockwave therapy, respectively. Pain intensity was chosen as the primary outcome measure. We standardized all the pain scores from different outcomes (VAS, NRS) to the same 0-10 scale (21). The process involves dividing the mean and standard deviation by the range of the original scale and subsequently multiplying the result by the range of the new scale (21). Lower extremity function as measured by LEFS scale was selected as the secondary measure. For all outcomes, data synthesis was done for different follow-up periods, short, medium and long-term, respectively. All primary and secondary outcomes comprised continuous data, allowing for the calculation of a standardized mean difference (SMD) and a 95% confidence interval (CI) in the meta-analysis using means and standard deviations, enhancing the generalizability of the findings and enabling assessment of studies that utilized varying scales to evaluate the same outcome

(22). Applying the random-effects model addressed the diversity among studies and its influence on the intervention. The variability between trials was assessed utilizing the I^2 statistic. A value of 25% indicates minimal heterogeneity, while 50% suggests moderate heterogeneity, and 75% signifies substantial heterogeneity (23). The data were represented through a forest plot.

RESULTS

Study selection

A thorough exploration of electronic databases yielded a combined total of 151 articles, of which 101 remained following the elimination of duplicates through the use of the EndNote reference manager. Through the initial screening process involving title and abstract review, 89 records were excluded. From the 12 full-text articles assessed for eligibility, 5 were deemed ineligible based on predefined inclusion criteria, resulting in the inclusion of 7 studies in this review. The reasons for the exclusion of the 5 articles were: 1) absence of ESWT administration (n = 1), 2) non-English language (n = 1), and 3) non-randomized study design (n = 3). **Figure 1** portrays a detailed depiction of the study selection process.

Study characteristics

The trials analyzed in this review encompassed 714 participants (refer to **table II**), with sample sizes varying across studies from 44 (24) to 229 (25), and participant ages ranging from 46 years (25) to 64 years (24). All included participants were adults diagnosed with GTPS. In the included studies, research was conducted in different countries and geographical regions, including Italy, United Kingdom, Spain, Turkey, among others.

Intervention

The characteristics of the intervention are illustrated in table 3. In four of the seven included trials (24, 26-28), focused ESWT was delivered while in the other three (25, 29, 30), radial ESWT was administered. In three of the RCTs (25, 28, 30), ESWT was given alone to the intervention group and in the remaining three RCTs, a home exercise program was also prescribed (26, 27, 29). In the single randomized cross-over trial included in this review, treatments were focused ESWT and eccentric therapeutic exercise, respectively (24). In all the trials, according to the guidelines, patients underwent three sessions of Extracorporeal Shock Wave Therapy (ESWT), which were administered once weekly over a period of three weeks.

Control/Alternative group

The efficacy of ESWT was assessed when compared with the control/alternative group that received sham ESWT in one article (27), and conventional non-surgical treatment in 6 studies (24-26, 28-30). Two studies incorporated in our systematic review investigated the efficacy of ESWT compared to corticosteroid injections for the management of GTPS (26, 30). One article compared the "recommended dose" ESWT to "minimal dose" ESWT (29). One trial compared ESWT with ultrasound therapy (28), while another made a comparison between the effects of Home Training, Local Corticosteroid Injection, and ESWT in patients with GTPS (25). In the randomized cross-over trial, ESWT was compared with eccentric therapeutic exercise (24) (**table III**).

Outcome measures

Various outcome measures were documented in the trials that were part of the study: Visual Analogue Scale (VAS), Numeric Rating Scale (NRS), Lower Extremity Functional Scale (LEFS), Harris Hip Score (HHS), Oxford Hip Score (OHS), Roles and Maudsley Scale (RMS), Non-Arthritic Hip Score (NAHS), GTPS version of the Victorian Institute of Sport assessment questionnaire (VISA-G), painDETECT, "Central sensitisation" (CSI), Pittsburgh Sleep Quality Index (PSQI), International Physical Activity Questionnaire (IPAQ), EuroQoL-5 Dimensions Questionnaire (EQ-5D), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), 36-Item Short-Form Health Survey (SF-36), and Likert Scales (**table II**).

Quality assessment

The evaluation of the methodological quality of the studies included is detailed in **table I**. All trials included in the analysis demonstrated a high level of methodological rigor, achieving a minimum score of 6 on the PEDro scale, with an average score of 6.14. With the exception of one study (25), all met the criteria for randomization, although concealed allocation was not mentioned in four studies. Baseline participant characteristics did not exhibit statistically significant differences across all studies (24-30). Assessors responsible for outcome measurement were blinded in all studies, while only one trial (29) blinded participants to group allocation. Therapists were not blinded to allocation in any of the studies (24-30). Furthermore, all included studies provided between-group statistical comparisons, as well as point estimates and measures of variability (24–30). As per the criteria, 5 studies (25-28, 30) included in our review demonstrat-

Table II. Characteristics of the included trials.

Author	Participants	Study design	Intervention	Comparison	Outcome measure	Result
Carlisi *et al.*, 2018	n = 50, GTPS pa-tients, I:26 (5M,21F) mean age: 61 ± 9.18 yrs C:24 (2M,22 F), mean age: 61.5 ± 9.52 yrs	Randomized-Controlled Trial	Focused extracor-poreal shock wave therapy once weekly for three weeks.	Ultrasound therapy for ten consecu-tive days around the most painful point of greater trochanter.	Pain: NRS, Function: LEFS.	Pain: f-ESWT was significantly more effective than UST at 2, 6-month fol-low-ups. LEFS: Both groups showed im-provements with no significant differ-ences.
Heaver *et al.*, 2021	n = 104 (10M, 94F), GTPS patients, I:53, mean age: 63.73 ± 11.87 yrs C:51, mean age: 60.31 ± 12.74 yrs	Randomized-Controlled Trial	Focused extracor-poreal shock wave therapy was given once a week for three weeks.	Corticosteroid in-jections targeting bursae and tendon insertions but avoiding intramus-cular or intraten-donous injections.	Pain: VAS, Local function: HHS and Trendelenburg test, Quality of life: SF-36, Likert scale of symp-tom improvement.	Both groups had im-provement in pain, function, QoL scores at 3 months, with no statistical differ-ences found be-tween them. At 12 months, ESWT group had shown signifi-cant improvement in all outcome measures as against control group.
Rompe *et al.*, 2009	n = 229, GTPS pa-tients, I: 78 (23M, 55 F) mean age: 45 yrs C1: 75 (21M, 54F), mean age: 50 yrs C2:76 (23M, 53F), mean age: 46 yrs	Quasi-Ran-domized-Controlled Trial	Radial extracorpo-real shock wave therapy was ad-ministered in three weekly sessions.	Corticosteroid In-jection: at point of maximal swelling around the greater trochanter.	Degree of recovery: Likert scale, Pain: NRS at 1, 4, and 15 months after treat-ment.	ESWT was less effective than CS injection after 1 month. By 4 months, ESWT showed sig-nificant results over home training. At 15 months, ESWT had similar efficacy to home training & su-perior efficacy compared to CS in-jection.
Notarnicola *et al.*, 2023	n = 44, GTPS Pa-tients, Group A: 22(10M,12F) Mean age: 59.1 ± 9.6 yrs Group B: 22(9M,13F) Mean age: 59.5 ± 7.7 yrs Group C: 7(3M, 4F) Mean age: 64.0 ± 12.7 yrs, Group D: 7(0 M,7 F), mean age: 52.1 ± 13.1 yrs	Randomized-Crossover Trial	Patients in Groups B and C underwent focused shock-wave therapy one session per week for three weeks.	Home program: Pi-riformis & Iliotibial band stretch, standing straight leg raise, Wall squat, Gluteal strengthening twice daily, 7 days/week, for 12 weeks.	Pain: NRS, Function: LEFS, Perceived re-covery: RMS.	All groups exhibited a gradual improve-ment in NRS score, LEFS, RMS within a six-month timeframe. No sig-nificant variations were observed among the four pro-tocols.

Author	Participants	Study design	Intervention	Comparison	Outcome measure	Result
Wheeler *et al.*, 2022	n = 120, GTPS pa-tients I: 57 (8M,49 F), mean age:61.7 ± 12.3 yrs C: 63 (15M, 48F), mean age: 60.0 ± 10.8 yrs	Randomized-Controlled Trial	Radial extracorpo-real shock wave therapy (rESWT) was given once per week for three weeks, the energy dose (pressure waves) being set at a "maximal com-fortably tolerated" level.	The exercise pro-tocol entailed ses-sions 5 days per week for 4 weeks, totaling 20 ses-sions.	Pain: NRS, Local function: OHS, non-arthritic hip score, GTPS version (VISA-G), Quality of life: EQ-5D-5L, Neuro-pathic pain: DETECT or "Central sensiti-zation", Sleep quali-ty: PSQI, Physical activity: IPAQ and 2 "vital signs" physical activity questions.	Both groups experi-enced statistically significant within-group improvement in pain, local func-tion, and sleep. Also, only a few benefits seen in activity & mood status. There were no time*group interaction effects reported at any point of time.
Ramon *et al.*, 2020	n = 103, GTPS pa-tients, I:53(11M,42F), mean age:57.1 ± 12.9 yrs C:50(18M,32 F), mean age:55.6 ± 11 yrs	Multicenter Randomized-Controlled Trial	Focused extracor-poreal shock wave therapy was ad-ministered for three weekly ses-sions. A home-specific exercise program once a day for twenty-four weeks.	Sham F-ESWT was administered for three weekly ses-sions & the same home-specific program once a day for twenty-four weeks.	Primary outcome: VAS, Secondary out-comes: Function: HHS & LEFS, Quality of life: EQ-5D, Per-ceived recovery: RMS.	The mean VAS score improved in both groups at two months. All second-ary outcomes at all follow-up intervals were significantly better in the f-ESWT group. LEFS score at one month wasn't significantly better.
Yağcı *et al.*, 2023	n = 64 GTPS pa-tients I32(5M27F) mean age50 ± 9.1yrs C32(7M21F) mean age51.7 ± 7.7yrs	Randomized Controlled Trial	Shock wave thera-py was adminis-tered. Patients un-derwent one ses-sion per week for three weeks focus-ing on the greater trochanter area.	Corticosteroid in-jection was ad-ministered the in-jection was ad-ministered verti-cally at the most sensitive point on the greater tro-chanter.	Pain: NRS, VAS for lateral hip pain and tenderness intensity at greater trochan-ter, WOMAC, Quality of life: SF-36	At three weeks and three months both groups showed sig-nificantly lower scores with no sig-nificant difference in treatment effica-cy. Similarly im-provements in SF-36 subscales were sim-ilar between groups.

GTPS: Greater Trochanteric Pain Syndrome; M: Males; F: Females; I: Intervention group; C: Control group; f-ESWT: Focused Extracorporeal Shock Wave Therapy; r-ESWT: Radial Extracorporeal Shock Wave Therapy; UST: Ultrasound Therapy; VAS: Visual Analog Scale; NRS: Numerical Rating Scale; LEFS: Lower Extremity Functional Scale; RMS: Roles-Maudsley Scale; HHS: Harris Hip Score; OHS: Oxford Hip Score; VISA-G: Victoria Institute of Sport - Gluteal score); SF-36: 36-Item Short Form Survey; EQ-5D: EuroQol 5 Dimension; PSQI: Pittsburgh Sleep Quality Index; IPAQ: International Physical Activity Questionnaire.

Table III. Selected studies and ESWT parameters.

Study	ESWT type	Number of pulses/shots	Energy/Pressure	Frequency (Hz)	Duration of session
Carlisi *et al.*, 2018	f-ESWT	1,800	0.05-0.15 mJ/mm²	4.0	NR
Heaver *et al.*, 2021	f-ESWT	2,500	0.15-0.35 mJ/mm²	-	NR
Rompe *et al.*, 2009	r-ESWT	2,000	0.12 mJ/mm²	8.0	NR
Notarnicola *et al.*, 2023	f-ESWT	2,000	0.03-0.17 mJ/mm²	4.0	NR
Wheeler *et al.*, 2022	r-ESWT	2,000	2.3 ± 0.3, 2.8 ± 0.3, 3.3±0.4 bar	20.0	NR
Ramon *et al.*, 2020	f-ESWT	2,000	0.20 mJ/mm²	5.0	NR
Yagci *et al.*, 2023	r-ESWT	2,000	2.0 bar	12.0	NR

ESWT: Extracorporeal Shock Wave Therapy; f-ESWT: Focused Extracorporeal Shock Wave Therapy; r-ESWT: Radial Extracorporeal Shock Wave Therapy; NR: Not reported.

ed good-methodological quality, having a PEDro score between 6-8. One study (29) had excellent methodological quality with a PEDro score of 9.

Assessment of risk of bias

The majority of the trials analyzed indicated minimal risk of bias stemming from the randomization process (24, 26-30). Conversely, only one study demonstrated a high risk in this aspect (25). In assessing bias related to deviation from the intended intervention, one out of the seven studies was identified with a high risk (26), while two studies (25, 30) had some concerns in this regard. Regarding bias from missing outcome data, six studies were deemed low risk, with one study having "some concerns" (25). All studies were classified as low risk for bias stemming from outcome measurement (24-30). Examination of bias resulting from selection of reported results indicated low risk across all studies. Additionally, the risk of bias analysis of randomized cross-over trials includes a separate domain (DS) regarding the bias arising from carryover effects. The single randomized cross-over trial included in our review (24) demonstrated "some concerns" for this domain (**figure 3**). The overall risk of bias in the included trials was as follows: low risk of bias in three studies, some concerns in two studies, and high risk of bias in two studies (**figures 2** and **3**).

Studies with high risk of bias may have introduced variability in the results of our review, leading to increased heterogeneity and may make it difficult to draw consistent conclusions.

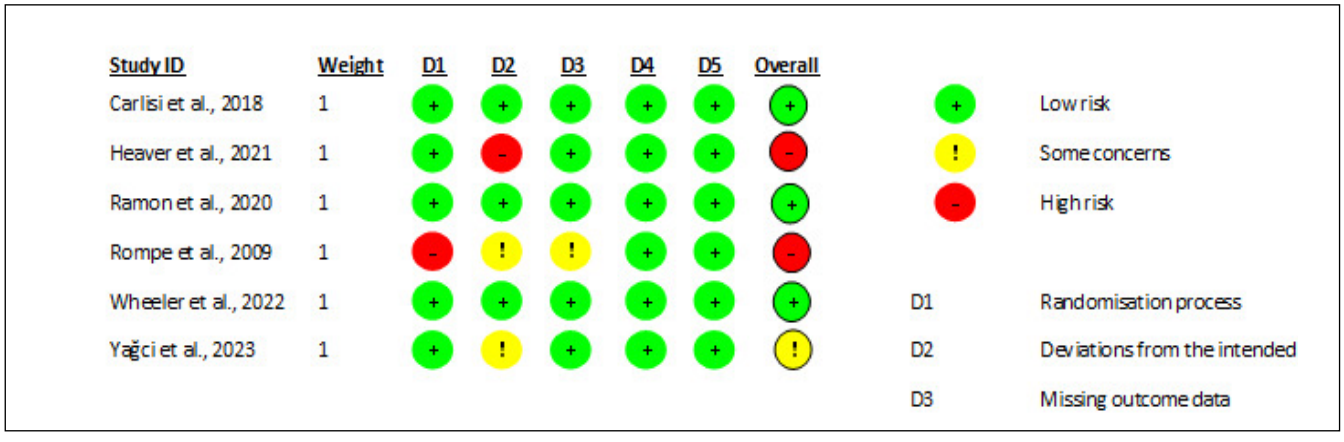

Figure 2. Risk of Bias Assessment of Randomized Controlled Trials.
Risk of bias assessment for RCTs using Cochrane's Risk of Bias 2 (ROB 2) tool.

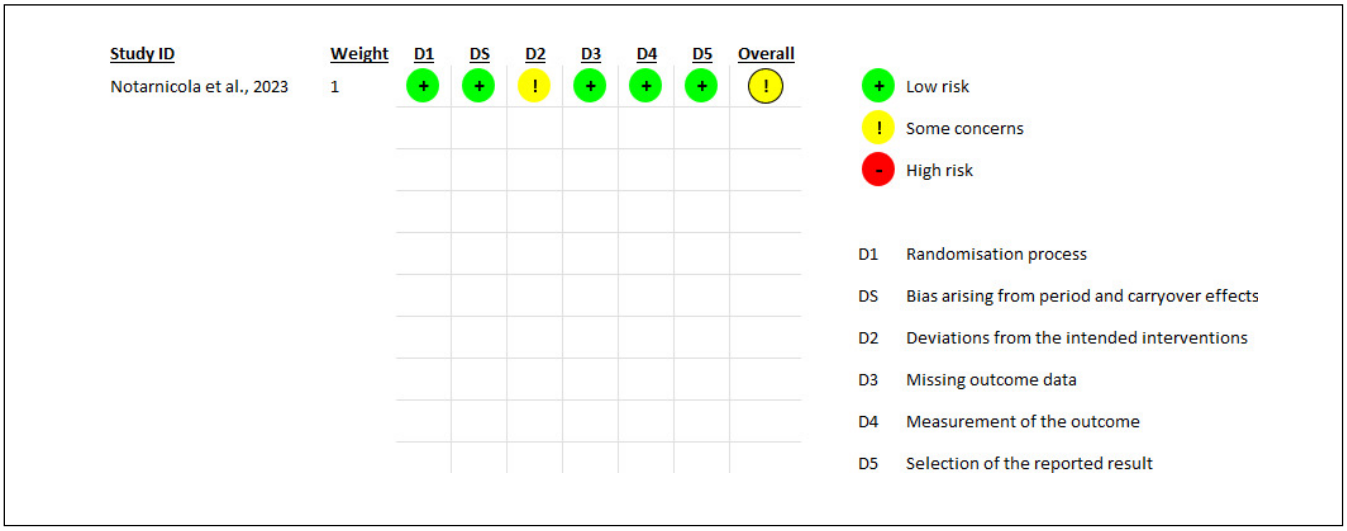

Figure 3. Risk of Bias Assessment of Randomized Cross-over Trials.
Risk of bias assessment for randomized cross-over trials using Cochrane's Risk of Bias 2 (ROB 2) tool.

Effects of intervention

Pain

All the seven selected studies examined the effects of ESWT on pain intensity measured using the VAS or the NRS (24-30).

ESWT vs ultrasound therapy

In one trial, participants were allocated to receive either f-ESWT or ultrasound therapy (UST) (28). Both groups showed significant pain reduction over time. However, f-ESWT was significantly more effective than UST at 2 and 6 months, respectively.

ESWT vs corticosteroid injections

Two randomized controlled trials compared the efficacy of ESWT for GTPS *versus* corticosteroid (CS) injections. Among these, one trial (26) did not show any significant difference in pain reduction levels between the groups at 3 months, but at the 12-month mark the ESWT group had significantly lower pain levels than the CS group. The other trial (30) reported that across all studied time intervals, there was no significant difference between the groups.

ESWT vs Sham

A different trial (27), where treatment group received f-ESWT, and control received sham therapy, there was a comparatively significant reduction in pain levels in the f-ESWT group at the 2-month follow-up.

ESWT vs other conservative treatment options

In a trial (25), patients were allocated to a home training program, a single local CS injection, or repetitive low-energy r-ESWT group. Assessments occurred at baseline, and at 1, 4, and 15 months. The study indicated significant improvement in the corticosteroid group after one month, surpassing home training and ESWT. However, this effect was not prolonged. Radial ESWT and home exercise program demonstrated superior outcomes at one year compared to the CS treatment. Participants in another study (29) were randomly assigned to receive three sessions of r-ESWT at either the "recommended" dose or at a "minimal dose." Follow-up evaluations were conducted at 6 weeks, 3 months, and 6 months. Here, no time X group interaction effects were observed between the groups, indicating no advantage of recommended-dose ESWT over minimal dose. Finally, in a cross-over trial (24), over the span of six months, all participants in the study exhibited a decline in pain levels as per the NRS, with no significant difference among the four protocols (eccentric exercise; ESWT; eccentric exercise + ESWT; and ESWT + eccentric exercise).

Lower extremity function

Lower extremity function was assessed by reliable tools like the Lower Extremity Functional Scale (LEFS) in three of the included studies.

ESWT vs ultrasound therapy

In one study (28), the LEFS score across all follow-ups after the ESWT treatment showed no significant difference compared to US therapy.

ESWT vs Sham

In the other study (27), a statistically significant improvement in the LEFS score was observed in the ESWT group compared to the control group, at the 2, 3, and 6 month follow-ups, but not at the 1 month follow-up.

ESWT vs eccentric exercises

In the cross-over study (24), the LEFS scores between the groups did not show any significant difference across any time point even though there was an improvement across all of them.

Treatment satisfaction

In studies involving ESWT interventions, the Roles-Maudsley Scale (RMS) is commonly used as an assessment tool for treatment outcome satisfaction (27, 29, 31). In our review, two of the included studies reported the RMS data. In one study (29), no statistically significant difference was seen in the RMS score between the groups. Conversely, the other study (27) reported statistically significant differences in the RMS scores between the treatment and the control groups on all follow-ups.

Meta-analysis: ESWT *vs* control/alternative group

Pain intensity

Radial shockwave therapy

As shown in **figure 4**, the pooled effect estimates between the short, medium, and the long-term follow-ups including 1277 participants from three studies (25, 29, 30) (SMD= -0.03; 95%CI -0.41 to 0.35; Z = 0.16, P = 0.87) showed that radial shockwave therapy did not have any statistically significant effect in decreasing the pain intensity in patients with GTPS compared to the control/alternative group. The analysis of heterogeneity, based on the degree of inconsistency observed between the results of the studies (I^2 = 91%,

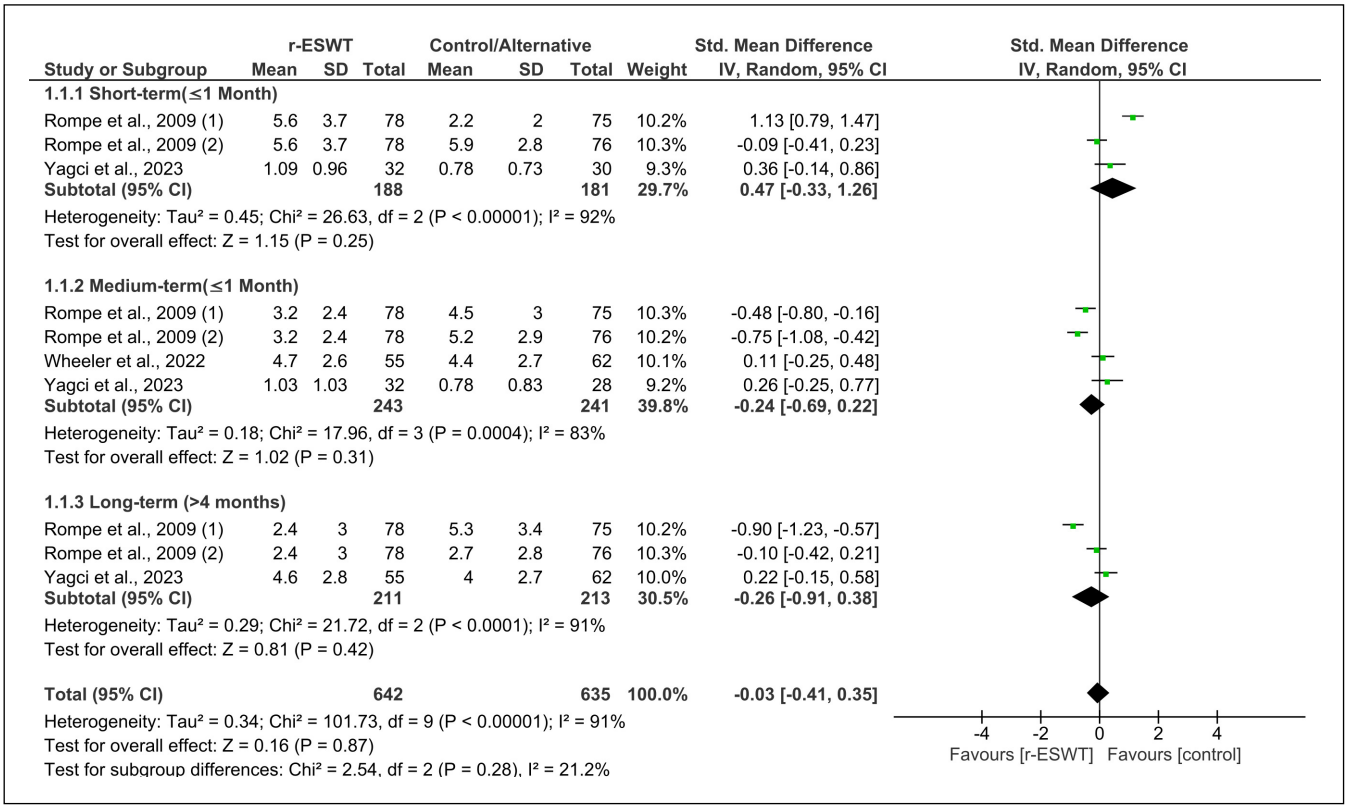

Figure 4. Pooled Analysis for Pain Intensity (r-ESWT *vs* Control).
Quantitative analysis of trials investigating the effect of r-ESWT on pain intensity.

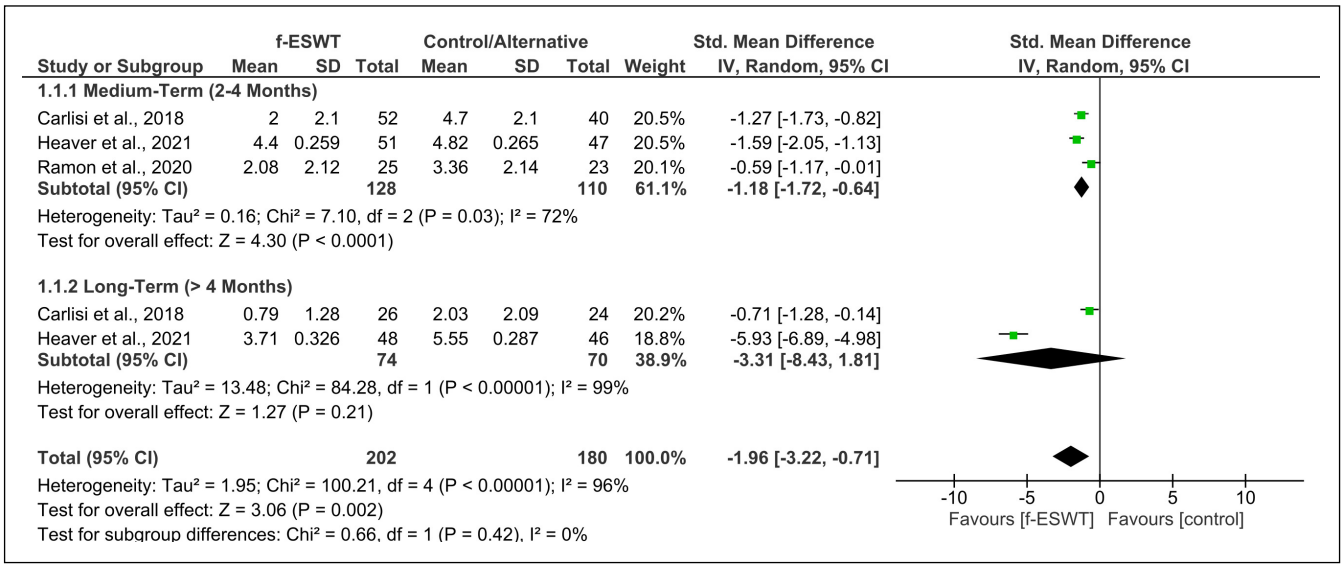

Figure 5. Pooled Analysis for Pain Intensity (f-ESWT *vs* Control).
Quantitative analysis of trials investigating the effect of f-ESWT on pain intensity.

P<0.00001), suggested that the level of heterogeneity was significantly high.

Short-term (≤ 1 Month)

The meta-analysis of the pain endpoint included two studies (25,30), comparing radial shockwave therapy with the control/alternative group in the short-term (≤ 1 Month). The studies showed significant heterogeneity (I^2 = 92%, p < 0.00001) (**figure 4**), and a had a total sample of 369 subjects. The findings indicated that there was no significant difference in pain intensity between the control group and the radial shockwave therapy group in the short term (SMD = 0.47; 95%CI -0.33 to 1.26; Z = 1.15, p = 0.25).

Medium-Term (2-4 Months)

Three studies (25, 30) were included in the meta-analysis of the pain endpoint, comparing radial shockwave therapy with control/alternative group at medium-term (2-4 Months) (**figure 4**), with a sample size of 484 subjects. Significant heterogeneity (I^2 = 83%, P < 0.0004) was reported. There was no significant difference in pain intensity between the radial shockwave therapy group and the control group in the medium-term (SMD = -0.24; 95%CI -0.69 to -0.22; Z = 1.02, p = 0.31).

Long-Term (> 4 Months)

Two studies (25, 29) were included in the meta-analysis of the pain endpoint, comparing radial shockwave therapy with control/alternative group at long-term (> 4 Months) (**figure 4**), with a sample size of 424 subjects. Significant heterogeneity (I^2 = 91%, p < 0.0001) was reported. There was no significant difference in pain intensity between the radial shockwave therapy group and the control group in the long-term (SMD = -0.26; 95%CI -0.91 to -0.38; Z = 0.81, p = 0.42).

Focused shockwave therapy

As shown in **figure 5**, the pooled effect estimates between the medium, and the long-term follow-ups including 382 participants from three studies (26-28) (SMD = -1.96; 95%CI -3.22 to -0.71; Z = 3.06, p = 0.002) showed that focused shockwave therapy has a statistically significant effect in decreasing the pain intensity in patients with GTPS compared to the control/alternative group. The analysis of heterogeneity, based on the degree of inconsistency observed between the results of the studies (I^2 = 96%, p < 0.00001), suggested that the level of heterogeneity was significantly high.

Medium-Term (2-4 Months)

Three studies (26-28) were included in the meta-analysis of the pain endpoint, comparing focused shockwave therapy with control/alternative group at medium-term (2-4 Months) (**figure 5**), with a sample size of 238 subjects. Significant heterogeneity (I^2 = 72%, p = 0.03) was reported. There was a significant difference in pain intensity between the radial shockwave therapy group and the control group

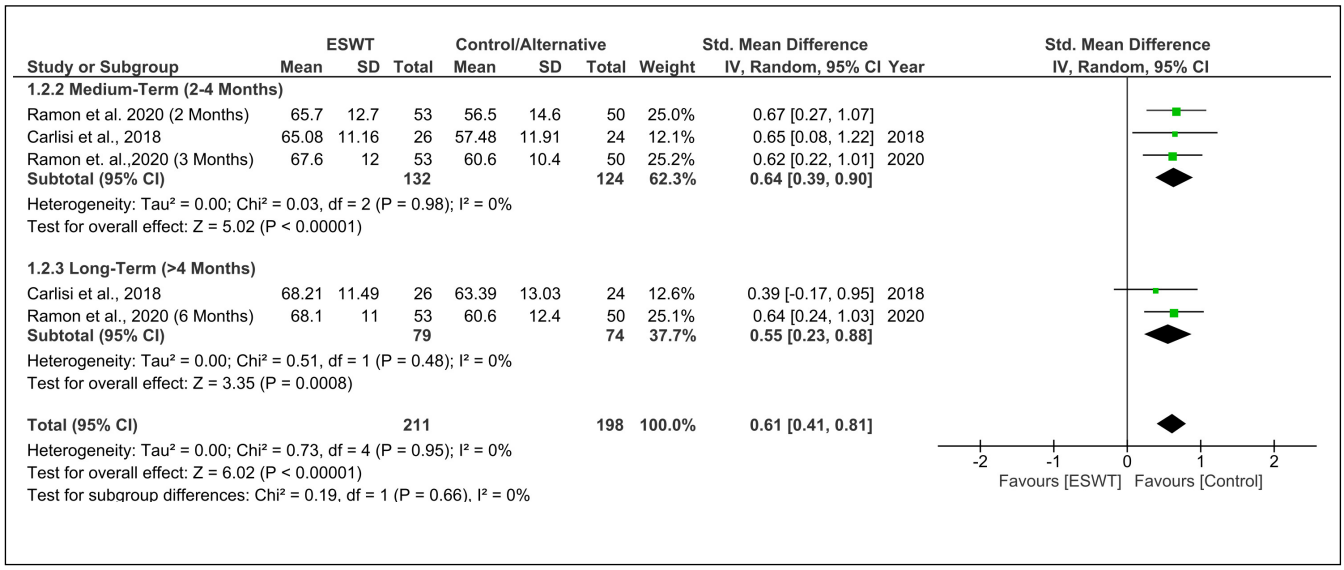

Figure 6. Pooled Analysis for Lower Extremity Function.
Quantitative analysis of trials investigating the effect of f-ESWT on lower extremity function.

in the medium-term (SMD = -1.18; 95%CI -1.72 to -0.64; Z = 4.30, p < 0.0001).

Long-Term (> 4 Months)

Two studies (26, 28) were included in the meta-analysis of the pain endpoint, comparing focused shockwave therapy with control/alternative group at long-term (> 4 Months) (**figure 5**), with a sample size of 144 subjects. Significant heterogeneity (I^2 = 99%, p < 0.00001) was reported. There was no significant difference in pain intensity between the focused shockwave therapy group and the control group in the long-term (SMD = -3.31; 95%CI -8.43 to 1.81; Z = 1.27, p = 0.21).

Lower extremity function

Focused shockwave therapy

As shown in **figure 6**, the pooled effect estimates from two studies (27, 28) with 409 participants (SMD = 0.61; 95%CI 0.41 to 0.81; Z = 6.02 p < 0.00001) depicted that ESWT was significantly better than control/alternative interventions in the medium and the long-term in improving lower limb functionality in GTPS. When heterogeneity was analyzed by the degree of inconsistency (I^2 = 0%, p = 0.95), the observed heterogeneity was not significant.

Medium-Term (2-4 Months)

Two RCT studies (27,28) with 256 participants provide information of a statistically significant difference, favouring the ESWT group, associated with the effects of ESWT on lower extremity function compared to control/alternative group in the medium-term (SMD = 0.64; 95%CI 0.39 to 0.90); Z = 5.02, p < 0.00001). The meta-analysis revealed insignificant heterogeneity (I^2 = 0%, p = 0.98) (**figure 6**).

Long Term (>4 Months)

Two RCT studies (27, 28) (n = 153 participants) provide information of a statistically significant difference, favouring the control/alternative group, associated with the effects of ESWT on lower extremity function compared to control/alternative group in the long-term (SMD = 0.55; 95%CI 0.23 to 0.88; Z= 3.35, p = 0.0008) (**figure 6**).

DISCUSSION

This review explored the impact of Extracorporeal Shockwave Therapy (ESWT) on alleviating symptoms of Greater Trochanteric Pain Syndrome (GTPS). It also compares how focused and radial shockwave therapy differ in their efficacy for treating GTPS. Prior to this study, there was a scarcity of systematic reviews conducting in-depth analyses to evaluate the effectiveness of ESWT in managing GTPS in affected individuals.

Pain

In the present meta-analysis, f-ESWT demonstrated superior efficacy in alleviating pain and enhancing physical

function compared to r-ESWT. The observed differences may be attributable to the distinct propagation characteristics, energy distribution, and inherent physical properties of f-ESWT and r-ESWT. Specifically, f-ESWT, generated through electromagnetic, electrohydraulic, or piezoelectric mechanisms, produces a concentrated beam, whereas r-ESWT, produced via pneumatic methods, exhibits a dispersed beam. The focused wave propagation of f-ESWT allows for deeper energy penetration into the target tissue, in contrast to r-ESWT (32). Moreover, r-ESWT lacks key shockwave features, including rapid rise time, high peak pressure, and non-linearity, which likely diminishes its therapeutic efficacy for GTPS (33).

There are various mechanisms that underline the excellent outcomes of trials demonstrating the use of ESWT for pain reduction in GTPS. By specifically harming unmyelinated fibers (33), reducing neuropeptides associated with pain (34), activating nociceptors, controlling pain neurotransmission (35), and reducing mediators of inflammation such as interleukins and matrixins, shockwave therapy effectively reduces musculoskeletal pain (36).

Gluteal tendinopathy is a major contributor to the development of GTPS. ESWT is widely used in conjunction with other treatments like exercise therapy to deliver impactful results in tendinopathy cases. ESWT exerts its effects on tendons and tendinopathy through various mechanisms. According to research, ESWT causes inflammatory and catabolic responses in tendons, which in turn cause tendon remodelling and the removal of harmed matrix elements (37). A key factor in starting these series of events that support tendon regeneration and healing is the mechanical stimulation that ESWT offers. Thus, such profound effects of shockwave at the tendon-level explain why it led to favourable outcomes in a condition like GTPS.

Lower Extremity Function

The meta-analysis indicates a significant contrast between the ESWT and control groups regarding LEFS scores. The analysis favors the ESWT group, suggesting that participants in this group demonstrated better outcomes in terms of LEFS scores compared to those assigned to the control/alternative treatment. A higher score on the LEFS indicates better functional performance or condition. It is already known that ESWT can potentially improve muscular tone, recruitment, elasticity, *etc.*, (38), a possible mechanism influencing limb function after the intervention. Also, ESWT has been discovered to have a beneficial effect on tendinopathy by stimulating tissue regeneration and amplifying the signaling mechanisms associated with angiogenesis (39). These actions hold the potential to enhance the functionality of the lower limbs in patients with GTPS. Two studies were included in the meta-analysis, where one study (28) did not find any statistically significant effect of ESWT on lower extremity function at any follow-up, while the second study (27) found that ESWT was significantly more effective than the control intervention at all studied time-points. This inconsistency might be ascribed to the specificity of the ESWT protocols employed, individual characteristics of the participants, and variances in the treatment provided to the comparator groups. However, the existing evidence emphasizes the necessity for additional research to elucidate the optimal treatment parameters and protocols that would most effectively enhance functionality in patients with Greater Trochanteric Pain Syndrome (GTPS).

The Roles and Maudsley score was categorized as excellent, good, acceptable, or poor based on the subjective satisfaction levels reported by patients following their treatments. Significantly higher patient satisfaction levels were reported in the studies where patients underwent shockwave treatment, be it radial or focused, as compared to the control/alternative groups. These findings regarding the high treatment outcome satisfaction levels after shockwave intervention align with the results reported in previous research conducted on different musculoskeletal conditions where ESWT treatment was offered (40-43). Shockwave's ability to address the underlying pathogenesis of the condition and providing effective pain management could be key factors in enhancing patient satisfaction. Calcific tendinopathy accounts for a majority of the gluteal tendinopathy-based cases of GTPS. It is thought that the shockwaves generated during ESWT treatment set off a three-pronged mechanism that involves molecular effects on deposit phagocytosis, mechanical effects on deposit fragmentation, and analgesic effects through desensitization of pain receptors (44). These effects help alleviate pain and reduce activity limitations, thereby contributing to higher treatment-related satisfaction among patients.

Shockwave *vs* some other popular treatment choices

When evaluating ESWT in comparison to corticosteroid injections for treating GTPS, patient preference is a significant consideration in determining the appropriate treatment. Corticosteroid injections are known for their

simplicity in administration and their ability to provide quick symptom relief. However, for patients who are allergic to local anesthetics or corticosteroids, or who are uncomfortable with injections, ESWT offers a viable alternative (30). It is also an effective option for those who do not respond to injection-based therapies. Importantly, while the effects of corticosteroid injections are generally short-term, ESWT has been shown to maintain its efficacy over a period of 2-4 months. Moreover, ESWT may be more appropriate for patients whose condition is primarily characterized by tendinopathy rather than bursitis (30).

Physiotherapy interventions, particularly exercise therapy, have long been central to the management of GTPS. Although therapeutic exercise is generally considered effective, standardized protocols regarding the optimal intensity, frequency, duration, and type of exercises are not yet well-established. Most treatment plans incorporate a mix of eccentric and concentric exercises, as current evidence does not clearly favor one approach over the other. Conservative interventions that induce structural changes in the tendon are especially beneficial in the treatment of tendinopathies, making them relevant in the context of GTPS management (24). In addition to exercise therapy, shockwave therapy has increasingly become a significant component of conservative treatments for tendinopathies. Therefore, the combination of exercise therapy and shockwave treatment presents a promising approach for the effective management of GTPS.

Clinical implications

The clinical implications of this review are substantial. Presently, there is no established treatment protocol for greater trochanteric pain syndrome (GTPS), making the selection of an effective therapeutic approach for symptom relief critical for clinicians. In this context, shockwave therapy, particularly focused shockwave therapy (f-ESWT), emerges as a promising intervention. Not only does f-ESWT significantly contribute to pain management, but it also enhances the functional status of patients with GTPS. In a scenario where there is an absence of definitive conservative treatment strategies, the review advocates for the use of f-ESWT over r-ESWT to achieve optimal clinical outcomes. Furthermore, the review emphasizes the high success rate of f-ESWT in the medium term (2-4 months), a period during which the efficacy of other conservative treatments typically diminishes, as evidenced by the majority of studies in the field (25-30). Previous clinical studies on various tendinopathies have also demonstrated that significant symptom improvement, when attained within three to twelve weeks following focused shock wave therapy, was typically sustained at the one-year follow-up (45). Consequently, f-ESWT represents a viable, effective, and safe alternative for the management of GTPS.

However, it's important to acknowledge the limitations of this review as well. Firstly, the meta-analysis is based on a relatively small number of studies with limited sample sizes, which might impact the generalizability of the findings. Furthermore, focusing solely on English-language studies may have excluded relevant studies published in other languages, potentially influencing the overall conclusions. Moreover, the variability in ESWT treatment protocols across the included studies, as well as differences in interventions administered to the comparator groups, contribute to the observed heterogeneity in the meta-analysis results. Our findings are somewhat aligned with the widely held scientific beliefs regarding the positive effects of shockwave in conditions like GTPS. While we have only included legitimate trials regardless of their results, the availability of very few studies on these lines may lead to a possible publication bias.

Future perspective

Future research should aim to expand the evidence supporting the effectiveness of ESWT in treating GTPS. This could involve including a wider variety of randomized controlled trials, particularly those investigating the long-term effects of ESWT on pain, functionality, quality of life, gluteal muscle strength, etc. Longer follow-ups are required for a chronic and often refractory condition like GTPS to advocate for the efficacy of ESWT as a necessary treatment modality for this condition.

Research should also explore the possibility of combining more treatment options with ESWT when targeting a condition like GTPS. This way, a more definitive treatment protocol can emerge which covers all possible areas of concern that escalate the symptoms in patients suffering from the condition.

For standardization of purposes, a detailed analyses focusing on specific ESWT parameters, such as type, frequency, intensity, and their optimal application for different GTPS patient groups are essential. Any recommendation regarding treatment parameters has not been standardized yet for GTPS. Hence, to guide and help practitioners choose this modality for effective treatment, such research is required. Tackling these aspects will not just enhance our comprehension of the therapeutic capabili-

ties of ESWT but also aid in crafting more precise and efficient rehabilitation approaches for individuals afflicted with GTPS.

CONCLUSIONS

The systematic review and meta-analysis conducted a thorough examination of the effectiveness of ESWT in individuals suffering from GTPS. It was found that ESWT could potentially provide notable advantages in reducing pain intensity, lower extremity function, and treatment satisfaction levels in patients with GTPS. The study should be seen in light of its limitations, where considering the heterogeneity due to variations in ESWT protocols, interventions given to comparator groups, small number of included studies, *etc.*, is essential.

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None.

DATA AVAILABILITY

Data are available along with the review.

CONTRIBUTIONS

ADA, AG., CAS, SS, SR: conceptualization. ADA, AG: writing – review & editing. All authors: writing – original draft.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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