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Original Article

Clinical effects of TECAR therapy in the conservative management of Stage 2 lipedema in females: A randomized controlled trial

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ABSTRACT

Objectives: This study aimed to evaluate the clinical efficacy of transfer energy capacitive and resistive (TECAR) therapy in females with Stage 2 lipedema, focusing on limb circumference, pain, functional status, and quality of life.

Patients and methods: A prospective, randomized controlled trial was conducted with 30 female patients diagnosed with Stage 2 lipedema between September 2024 and May 2025. Participants were randomized to a TECAR group (n=15; mean age: 52.7±13.1 years; range 39 to 66 years) or a control group (n=15; mean age: 45.9±12.9 years; range, 37 to 59 years). Both groups received compression garments and a structured exercise program. The TECAR group additionally underwent six TECAR sessions over three weeks. Outcomes included lower limb circumference, Visual Analog Scale for pain, Lower Extremity Functional Scale, and Lymphedema Quality of Life Questionnaire-Leg, assessed at baseline and at one and three months after treatment.

Results: The groups were comparable at baseline for age (p=0.163) and body mass index (31.85±4.08 kg/m² in the TECAR group and 30.02±4.08 kg/m² in the control group; p=0.112). The TECAR therapy resulted in greater reductions in lower limb circumference compared to standard care, with a statistically significant and sustained improvement observed only in the supramalleolar region at three months (p<0.05). A significant short-term reduction in pain was observed at one month (p=0.003) only in the TECAR group, but this effect was not maintained at three months (p>0.05). Functional scores showed a nonsignificant trend toward improvement (p=0.058). The overall quality of life score improved significantly in the TECAR group (p=0.002), although no individual Lymphedema Quality of Life Questionnaire subdomain reached statistical significance (p>0.05).

Conclusion: As an adjunct to standard care, TECAR therapy appears to reduce pain and limb volume and enhance overall quality of life in Stage 2 lipedema. Further long-term studies are needed to confirm these findings.

Keywords: Lipedema, pain management, quality of life, TECAR therapy.

Lipedema is a chronic, progressive adipose tissue disorder that predominantly affects females and is characterized by a symmetrical and disproportionate accumulation of painful subcutaneous fat, primarily in the legs and, less commonly, in the arms. This condition is frequently accompanied by persistent pain, pressure sensitivity, and sensations of heaviness or tightness, often occurring independent of physical activity. Additional hallmark features include easy bruising due to capillary fragility and a nodular or lumpy texture of subcutaneous fat, particularly prominent in Stage 2 lipedema. Beyond its physical manifestations, lipedema is commonly associated with a substantial psychosocial burden, including body image dissatisfaction, social withdrawal, and a reduced quality of life (QoL).[1-3] The exact cause of lipedema remains unclear, and several hypotheses have been proposed to explain its pathophysiology. Current evidence suggests that the condition involves a multifactorial interplay of microvascular fragility with increased capillary permeability, chronic low-grade inflammation with elevated proinflammatory cytokines, fibrotic remodeling of subcutaneous tissues, genetic

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predisposition, hormonal influences (onset around puberty, pregnancy, and menopause), and the presence of microedema even without overt lymphedema.[3] Genetic susceptibility appears to play a role in lipedema, as familial occurrence has been identified in 15 to 64% of affected individuals.[4,5] Histopathological examinations commonly reveal adipocyte hypertrophy, perivascular inflammation, and fibrotic remodeling, supporting the concept of a complex disruption in local tissue homeostasis. These pathological mechanisms contribute to interstitial fluid accumulation, increased tissue stiffness, and nociceptive sensitization.[4,6,7]

The current management of lipedema involves a combination of conservative treatments and, when necessary, surgical interventions. Among conservative approaches, complex decongestive therapy remains the standard of care, including compression garments, manual lymphatic drainage, physical activity, and skin care, aimed at reducing symptoms and preventing progression. However, recent consensus guidelines emphasize that these components should not be regarded as universally applicable in equal measure. Compression therapy, particularly with flat-knit and custom-fitted garments, has emerged as the cornerstone of conservative management. It is strongly supported by evidence for reducing limb heaviness, improving mobility, and enhancing QoL and is recommended for daily, long-term use regardless of the presence of microedema.[3] In contrast, manual lymphatic drainage does not affect pathological adipose tissue and offers only limited benefit, primarily in terms of transient symptom relief. Its use is most appropriate in patients with significant pain, tenderness, or heaviness associated with microedema or subclinical lymphatic dysfunction. Accordingly, manual lymphatic drainage should be viewed as a selective, symptom-directed therapy, rather than a routine intervention for all lipedema patients.[1,3,5] Intermittent pneumatic compression and other physiotherapy-based interventions have shown benefit in selected patients, particularly for managing pain and edema.[8,9] Nutritional support and psychosocial counseling are also essential to enhance QoL and address the emotional burden frequently associated with the condition.[4] In more advanced stages, liposuction has proven to be the most effective surgical option for reducing fibrotic fat and improving pain and mobility. However, it is invasive and carries procedural risks.[5,10] Despite these available modalities, many patients continue to experience incomplete symptom relief and treatment fatigue. Given the complex pathology of lipedema and the limitations of current therapies, there is growing interest in adjunctive noninvasive physical treatments that address vascular, lymphatic, and connective tissue dysfunction.

Among the emerging therapeutic modalities in rehabilitation medicine, transfer energy capacitive and resistive (TECAR) therapy has gained increasing attention. This noninvasive diathermy technique operates using electromagnetic waves in the 0.3 to 1.2 MHz range to deliver deep tissue heating. It has been demonstrated to improve local blood circulation, enhance lymphatic drainage, reduce inflammation, and stimulate cellular metabolism, while also modulating tissue stiffness and pain perception.[11-13] Current evidence primarily supports the use of TECAR therapy in the treatment of various musculoskeletal disorders, including chronic nonspecific low back pain, tendinopathies, muscle injuries, knee osteoarthritis, and shoulder pathologies.[12,14-17] Additionally, emerging research highlights its therapeutic value in neurological conditions such as peripheral neuropathy, carpal tunnel syndrome, and post-stroke spasticity.[18-20] Beyond these established indications, preliminary evidence from a study on obese patients with lower extremity lymphedema suggests that TECAR therapy may lead to greater reductions in limb volume and improvements in pain and mobility compared to standard decongestive treatments.[13] Although lipedema and lymphedema are distinct conditions, with lipedema primarily involving symmetrical adipose deposition and lymphedema characterized by lymphatic obstruction and fluid accumulation, overlapping features (fibrotic changes, impaired microcirculation, and chronic inflammation) have been noted in the literature. While our study excluded patients with confirmed lymphedema, these shared pathological features support the rationale for exploring TECAR therapy in lipedema management. To the best of our knowledge, there is currently no published clinical research that specifically examines the therapeutic effects of TECAR therapy in patients with lipedema.

The present study aimed to evaluate the clinical effects of TECAR therapy in females with Stage 2 lipedema, focusing on key outcomes such as limb circumference, pain severity, functional status, and QoL. By targeting measurable clinical endpoints, this study sought to contribute novel evidence to

support the integration of TECAR therapy into comprehensive, multimodal treatment strategies for lipedema.

PATIENTS AND METHODS

This prospective, randomized controlled trial was conducted at the Physical Medicine and Rehabilitation Outpatient Clinic of the Ankara Bilkent City Hospital, Physical Medicine and Rehabilitation Hospital between September 2024 and May 2025. A total of 40 female patients who presented to the outpatient clinic with a preliminary diagnosis of lipedema were evaluated. All patients were clinically assessed by a physician experienced in lipedema and lymphatic disorders. The diagnosis was established based on internationally accepted clinical criteria as outlined in consensus guidelines, including the following: symmetrical and disproportionate fat accumulation in the lower extremities sparing the feet; onset or exacerbation during periods of hormonal flux, heightened sensitivity/pain to touch, or pain without pressure; easy bruising; palpable fat nodularity; ankle cuffing; and limited or no response to calorie-restricted dieting and exercise regimes.[1,21] Patients presenting with skin indentations ("peau d'orange" appearance), palpable subcutaneous nodules, and a nodular, uneven fat texture indicative of early fibrosis were classified as having Stage 2 lipedema.[5,21] Among the evaluated patients, 30 fulfilled the inclusion criteria and were enrolled in the study (Figure 1). Female patients aged 18 to 60 years with a clinical diagnosis of Stage 2 lipedema and a body mass index (BMI) <35 were included. Written informed consent was obtained from all participants. Approval for the study was granted by the Ankara Bilkent City Hospital Medical Research Scientific Ethics Committee (Date: 05.06.2024, No: TABED 1-24-324). The study was conducted in accordance with the Declaration of Helsinki and registered on Clinical Trials (NCT: 07088315). The study adhered to the principles of the CONSORT guidelines.

Exclusion criteria comprised: deterioration in general condition, presence of open wounds or sensory deficits in the area of application, active infections, malignancy, autoimmune or systemic inflammatory diseases (e.g., rheumatoid arthritis or systemic lupus erythematosus), severe cognitive impairment, uncontrolled chronic systemic disease, history of physiotherapy or regular nonsteroidal anti-inflammatory drug use within the last six months, and concomitant lymphedema or venous insufficiency. To exclude lymphedema, all patients underwent a comprehensive clinical evaluation for signs suggestive of the condition, such as foot involvement, asymmetric swelling, and a positive Stemmer's sign. In patients where findings raised clinical suspicion, lymphoscintigraphy was performed to confirm or exclude lymphedema. Furthermore, venous duplex ultrasonography was performed on all participants by an experienced radiologist to exclude venous insufficiency.

The participants were randomly divided into two groups using the closed envelope method. They were blinded to group assignment. An independent individual who was not involved in the study created the treatment allocations. Patients were randomly assigned to the TECAR (n=15; mean age: 52.7±13.1 years; range 39 to 66 years) or control (n=15; mean age: 45.9±12.9 years; range, 37 to 59 years) group using sealed, opaque envelopes. Once a patient agreed to participate in the study, an envelope was opened, and the treatment was assigned to the patient. Sociodemographic and clinical characteristics of the patients, such as age, sex, BMI, and comorbidities, were recorded. Clinical assessments were conducted at baseline, as well as at one and three months following the treatment.

All participants were provided with individually fitted, Class II (23-32 mmHg) compression leggings, prescribed based on limb volume, individual tolerance, and current clinical guidelines for Stage 2 lipedema.[5,22] The patients were instructed to wear them during waking hours for a minimum of 8 h per day. Adherence to garment usage was monitored through patient diaries and reinforced at follow-up visits.

Additionally, all patients were advised to engage in a structured walking program, consisting of moderate-intensity walking (perceived exertion level 11-13 on the Borg scale), for at least 20 min per session, three times per week. The control group received standard care consisting of exercise and compression garment. The treatment group received the same standard care plus TECAR therapy.

TECAR therapy

In this study, TECAR therapy was applied to the lower limbs of patients diagnosed with lipedema using the BTL-6000 TR-Therapy PRO device (BTL, Ankara, Türkiye; manufactured in 2019). All treatment

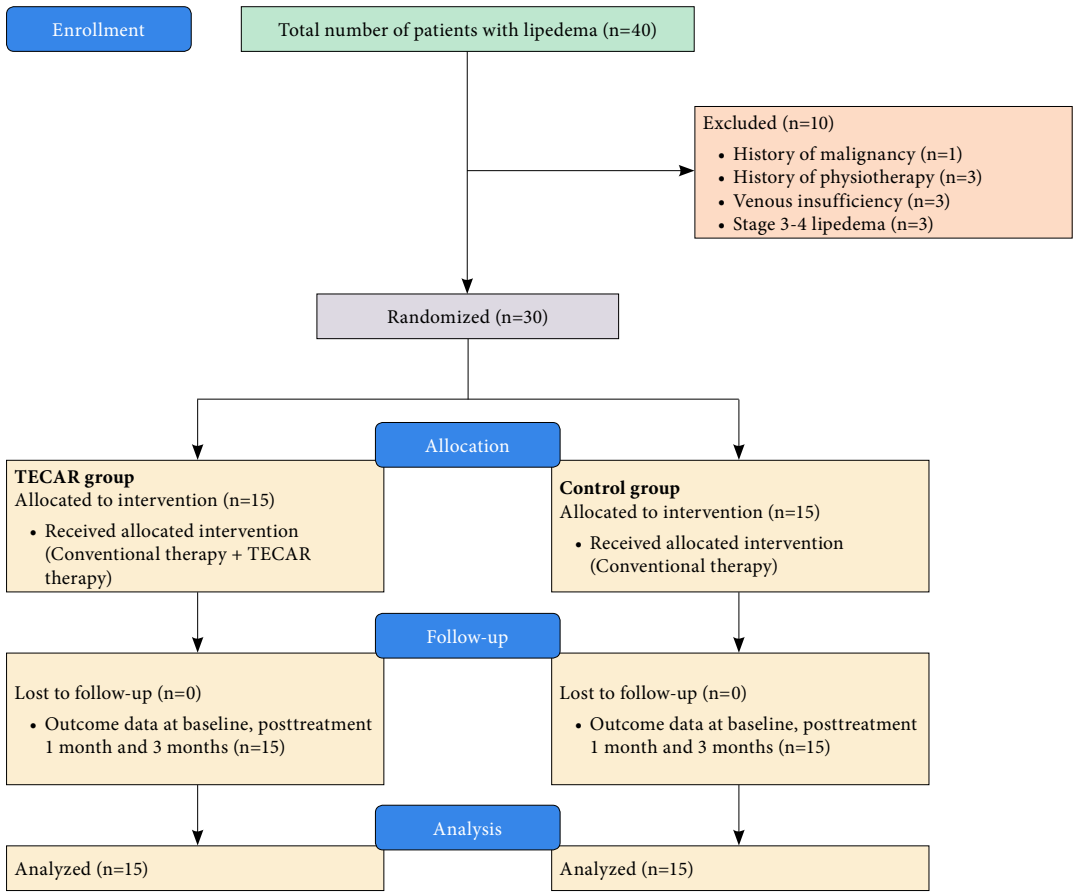

Figure 1. Flow diagram of the study.
TECAR: Transfer energy capacitive and resistive.

sessions were performed by a physiotherapist with specific experience in TECAR therapy. The device operated at a frequency of approximately 500 kHz and employed three types of electrodes: active, neutral, and static application electrodes. Two types of active electrodes (capacitive and resistive) were utilized and applied directly to the treatment area. The neutral electrode, serving as a reference point, was placed in proximity to the target region to ensure effective energy transfer.

Patients were positioned comfortably in either supine or prone positions, depending on the treatment area, to allow full access to the lipedema-affected regions of the lower limbs while ensuring relaxation and stability. Before each session, a layer of conductive gel was applied over the treatment area, typically the thighs or calves affected by lipedema, to enhance energy transmission.

Treatment began with the capacitive electrode, aimed at superficial tissues such as the skin, subcutaneous fat, and superficial fascia, using gentle linear or circular movements for about 5 min. This was followed by the application of the resistive electrode for 10 min, targeting deeper fibrotic and connective tissue structures. Power output was individually adjusted to maintain a pleasant warmth without causing pain or discomfort. Each session lasted approximately 15 min. The TECAR therapy was administered two times per week for three weeks (total of six sessions).

Outcome measures

Circumference measurements were performed using a standard nonelastic tape measure at three anatomically defined landmarks: the mid-thigh, identified as the midpoint between the iliac crest and the lower border of the patella, and the pretibial region, defined as the midpoint between the anterior tibial tuberosity and the medial malleolus and supramalleolar region. These regions were selected for their clinical relevance

in lipedema and their high reproducibility in anthropometric assessments.[23] To enhance measurement reliability, each site was measured three times consecutively, and the mean value was used for analysis. All measurements were conducted with the patient in a relaxed standing position by the same examiner to minimize interobserver variability.

Pain intensity was assessed using the Visual Analog Scale (VAS) based on pain provoked by moderate manual pressure applied with the examiner's thumb to the most symptomatic area of the lower limb. The same clinician performed all assessments using a consistent technique to ensure standardization across participants and time points. The VAS is a 10-cm horizontal line representing a continuum of pain experience, where 0 indicates "no pain" and 10 denotes the "worst imaginable pain."[24] Participants were asked to mark the point that best reflected their pain perception at each evaluation time point.

Functional status was evaluated using the Lower Extremity Functional Scale (LEFS), a widely validated, patient-reported outcome measure, specifically designed to assess lower extremity functional impairment. The LEFS consists of 20 items, each addressing a different daily or recreational activity involving the legs, such as walking, climbing stairs, squatting, or running. Participants rated the level of difficulty they experienced performing each activity on a 5-point Likert scale, ranging from 0 (extreme difficulty or unable to perform) to 4 (no difficulty). The total score ranges from 0 to 80, with higher scores reflecting greater functional capacity and less disability.[25]

Quality of life was assessed using the Lymphedema Quality of Life Questionnaire for the Leg (LYMQOL-Leg), a disease-specific instrument originally designed to evaluate health-related QoL in patients with lower limb lymphedema. The questionnaire includes 24 items grouped into four distinct domains: function (activities of daily living and physical capacity), appearance (self-perception of leg aesthetics), mood (emotional and psychological well-being), and symptoms (such as heaviness, swelling, and pain). Each item is scored on a Likert scale from 1 to 4, with lower scores indicating greater impairment. In addition to domain scores, the LYMQOL includes a global QoL score (rated on a scale from 0 to 10), where higher values reflect better overall QoL.[26,27] Although originally developed for lymphedema, LYMQOL has been effectively applied in lipedema studies due to symptom overlap.

Sample size determination

The sample size was determined using G*Power version 3.1.9.7 software (Heinrich-Heine Universität Düsseldorf, Düsseldorf, Germany) for a two-group repeated-measures design with three time points. Visual Analog Scale for pain at one month was designated as the primary outcome for sample size determination, as pain reduction is the most clinically relevant and patient-centered end point in Stage 2 lipedema rehabilitation. A moderate effect size (Cohen's d=0.5) was assumed, in line with Cohen's conventions and because no prior randomized controlled trials on TECAR therapy in lipedema were available to guide a more specific estimate. With an alpha of 0.05 and 80% power, the analysis indicated that 14 patients per group (28 in total) were required. To account for a potential dropout rate of approximately 10%, the target enrollment was increased to 15 patients per group (30 in total). Ultimately, all 30 patients completed the study.

Statistical analysis

All statistical analyses were performed using IBM SPSS version 27.0 software (IBM Corp., Armonk, NY, USA). Normality of continuous variables was assessed using the Kolmogorov-Smirnov test. Continuous variables were summarized as mean ± standard deviation (SD) for normally distributed data and as median (min-max) for nonnormally distributed data. The BMI values were categorized into clinically relevant subgroups and compared between groups using the chi-square test. Between-group differences in categorical comorbidity frequencies were evaluated with Fisher exact test. For intergroup comparisons, Student's t-test was used for normally distributed data, while the Mann-Whitney U test was applied for nonnormally distributed data. Within-group comparisons were analyzed using repeated measures analysis of variance (ANOVA) for normally distributed variables and the Wilcoxon signed-rank test for nonnormally distributed variables, with Bonferroni correction for post hoc analysis. In repeated-measures ANOVA, Mauchly's test was used to assess sphericity. When the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied, and results were reported accordingly. Given the exploratory nature of this

trial, no across-domain multiplicity adjustment was applied. A p-value <0.05 was considered statistically significant.

RESULTS

All 30 patients who met the inclusion criteria (TECAR group, n=15; control group, n=15) completed the treatment program and participated in both the first and third month follow-up assessments. All had type 3 lipedema, which is characterized by symmetrical fat accumulation in the hips, thighs, and lower legs, including the ankle region. The groups had no statistically significant difference regarding mean age (Student's t-test, p=0.163). The baseline BMI was 31.85±4.08 kg/m² in the TECAR group and 30.02±4.08 kg/m² in the control group (Student's t-test, p=0.112). When stratified by BMI subcategories, the distribution of the patients did not differ significantly between the groups (chi-square test, p=0.443; Table 1). No significant changes in BMI were observed in either group during the follow-up period (repeated measures ANOVA; TECAR group, p=0.070; control group, p=0.065), indicating stable weight throughout the intervention. The distribution of comorbidities was comparable between groups, with no statistically significant differences observed for hypertension, hypothyroidism, type 2 diabetes mellitus, osteoarthritis, or coronary artery disease (Fisher exact test, all p=1.000; Table 2). No adverse events or side effects related to TECAR therapy were reported by any participant during the study period.

Circumference measurements

No significant differences were observed between the groups at baseline in mid-thigh, pretibial, and supramalleolar circumferences. During follow-up, both groups showed significant reductions in mid-thigh and pretibial measurements (p<0.05). However, a significant decrease in supramalleolar circumference was observed only in the TECAR group (bilaterally p<0.001). Furthermore, at one month, the TECAR group demonstrated significantly greater reductions in all measured regions (mid-thigh, pretibial, and supramalleolar) compared to the control group (p<0.05). These differences were partially maintained at three months, with statistically significant reductions persisting only in the bilateral supramalleolar region (p<0.05; Table 3).

TABLE 1
Baseline BMI subgroup analysis

	Control group (n=15)		TECAR group (n=15)	
BMI category	n	%	n	%
<25	3	20.0	1	6.7
25-29.9	3	20.0	2	13.3
30-34.9	9	60.0	12	80.0

BMI; Body mass index; Values are expressed as number of patients (percentage within group). Comparison between groups was performed using the chi-square test; Significance level p<0.05; no statistically significant difference was observed (p=0.443).

TABLE 2
Distribution of the comorbidities

	Control group (n=15)	TECAR group (n=15)
Comorbidities	n	n
Hypertension	4	3
Hypothyroidism	2	2
Type 2 DM	3	4
Osteoarthritis	2	2
Coronary artery disease	0	1

DM: Diabetes mellitus; Fisher's exact test; Significance level p<0.05; no statistically significant difference was observed (p=0.97).

TABLE 3
Intra- and intergroup comparisons of lower limb circumference measurements between the TECAR and control groups at baseline and follow-up

	TECAR group (n=15)			Control group (n=15)				Effect size	
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*	Cohen's d	95% CI
Pretibial circumference (right) (cm)									
Baseline	42.13±6.93			42.13±6.41			1.000*		
1st month	40.86±6.75			41.66±6.35			0.741*		
3rd month	40.86±6.75			41.26±6.34			0.868*		
p		*0.001***			*0.002***				
Δ1		−1	−3-0		0	−2-0	**0.032*****		
Δ2		−1	−3-0		−1	−2-0	0.345*****		
Pretibial circumference (left) (cm)									
Baseline	42.00±6.71			42.33±6.27			0.889*		
1st month	40.73±6.76			41.86±6.23			0.637*		
3rd month	40.80±6.86			41.33±6.27			0.826*		
p		**<0.001****			**0.002****				
Δ1		−1	−3-0		0	−2-0	**0.035*****		
Δ2		−1	−3-0		−1	−3-0	0.600*****		
Thigh circumference (right) (cm)									
Baseline	66.46±7.34			64.26±8.63			0.459*		
1st month	65.00±7.02			63.80±8.40			0.674*		
3rd month	65.00±7.02			63.20±8.50			0.532*		
p		**<0.001****			**0.003****				
Δ1		−1	−3-0		0	−2-0	**0.011*****		
Δ2		−1	−3-0		−1	−4-0	0.285*****		
Thigh circumference (left) (cm)									
Baseline	66.33±6.99			64.26±8.63			0.478*		
1st month	64.73±7.10			63.80±8.40			0.745*		
3rd month	64.66±7.08			63.26±8.48			0.628*		
p		**<0.001****			**0.004****				
Δ1		−2	−4-0		0	−2-0	**0.009*****		
Δ2		−2	−4-0		−1	−4-0	0.106*****		
Supramalleolar circumference (right) (cm)									
Baseline	25.00±3.16			25.60±3.41			0.662*		
1st month	24.06±3.41			25.46±3.35			0.267*	−0.41	−1.14, 0.31
3rd month	24.06±3.41			25.26±3.53			0.352*	−0.35	1.05, 0.35
p		**<0.001****			0.061**				
Δ1		−1	−2-0		0	−2-0	**0.002*****		
Δ2		−1	−2-0		0	−2-0	**0.026*****		
Supramalleolar circumference (left) (cm)									
Baseline	25.26±3.65			25.60±3.37			0.797*		
1st month	24.40±3.66			25.46±3.31			0.410*	−0.30	−1.02, 0.42
3rd month	24.46±3.58			25.26±3.47			0.540*	−0.23	0.95, 0.49
p		**<0.001****			**0.061****				
Δ1		-1	−2-0		0	−2-0	**0.016*****		
Δ2		-1	−2-0		0	−2-0	**0.030*****		

TECAR: Transfer energy capacitive and resistive; SD: Standard deviation; CI: Confidence interval; * Student's t-test; ** Repeated measures ANOVA (with Greenhouse-Geisser correction where sphericity was violated; Bonferroni adjustment applied for post hoc comparisons); *** Mann-Whitney U test; Δ1: Baseline-first month; Δ2: Baseline-third month.
Values represent mean±SD for each limb (right and left measured separately) at three anatomical sites (pretibial, thigh, and supramalleolar). No pooling or averaging across limbs or sites was performed. Significance level p<0.05, Significant p-values shown in bold. Between group differences reached statistical significance only at supramalleolar site.

Pain intensity

At baseline, pain intensity levels were comparable between the TECAR and control groups (6.46±1.80 *vs.* 6.60±1.45; p=0.825). Within-group analysis demonstrated a significant reduction in VAS scores in the TECAR group following treatment (p=0.003), whereas no significant change was detected in the control group (p=0.127). Post hoc comparisons revealed a significant improvement in the TECAR group between baseline and one month (p=0.003); however, changes between baseline and three months and between one and three months were not statistically significant (p=0.052 and p=1.000, respectively). Between-group comparisons indicated that the reduction in VAS scores was significantly greater in the TECAR group compared to the control group at both follow-up intervals: Δ1 (baseline-first month, p=0.001) and Δ2 (baseline-third month, p=0.023), suggesting a more favorable analgesic outcome with TECAR therapy (Table 4).

Functional status

Within-group analysis in the TECAR group showed a trend toward improved lower extremity functional scores over time, although this change did not reach statistical significance (p=0.058). In contrast, no significant improvement was observed in the control group (p=0.167). However, between-group comparison at one month revealed a significantly greater improvement in LEFS scores in the TECAR group compared to the control group (Δ1, baseline-first month, p=0.008). No statistically significant difference was found between the groups at three months (Δ2, baseline-third month, p=0.187; Table 5).

TABLE 4
Intra- and intergroup comparisons of pain severity scores between the TECAR and control groups at baseline and follow-up

	TECAR group (n=15)			Control group (n=15)				Effect size	
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*	Cohen's d	95% CI
VAS									
Baseline	6.46±1.80			6.60±1.45			0.825*		
1st month	4.86±1.92			6.26±1.27			**0.026***	−0.86	−1.61, −0.11
3rd month	5.13±1.76			6.20±1.14			**0.060***	−0.72	−1.46, 0.02
p		**0.003****			0.127**				
Δ1		−1	−6-0		0	−3-0	**0.001*****		
Δ2		−1	−6-3		0	−3-1	**0.023*****		

TECAR: Transfer energy capacitive and resistive; VAS: Visual analog scale; SD: Standard deviation; CI: Confidence interval; * Student's t-test; ** Repeated measures ANOVA (with Greenhouse-Geisser correction where sphericity was violated; Bonferroni adjustment applied for post hoc comparisons); *** Mann-Whitney U test; Δ1: Baseline-first month; Δ2: Baseline-third month. Significance level p<0.0, Significant p-values shown in bold.

TABLE 5
Intra- and intergroup comparisons of lower extremity function scores between the TECAR and control groups at baseline and follow-up

	TECAR group (n=15)			Control group (n=15)				Effect size	
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*	Cohen's d	95% CI
LEFS									
Baseline	45.73±18.23			49.13±13.80			0.569*		
1st month	49.86±16.57			49.53±12.59			0.951*	0.02	−0.69, 0.74
3rd month	49.33±16.62			50.13±12.44			0.882*	0.05	−0.77, 0.66
p		0.058**			0.167**				
Δ1		3	−9-22		0	−4-5	**0.008*****		
Δ2		3	−9-22		0	−4-5	0.187***		

TECAR: Transfer energy capacitive and resistive; LEFS: Lower extremity functional scale; SD: Standard deviation; CI: Confidence interval; * Student's t-test; ** Repeated measures ANOVA (with Greenhouse-Geisser correction where sphericity was violated; Bonferroni adjustment applied for post hoc comparisons); *** Mann-Whitney U test; Δ1: Baseline-first month; Δ2: Baseline-third month. Significance level p<0.0, Significant p-values shown in bold.

TABLE 6
Intra- and intergroup comparisons of LYMQOL-leg scores between the TECAR and control groups at baseline and follow-up

	TECAR group (n=15)			Control group (n=15)				Effect size	
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*	Cohen's d	95% CI
Function									
Baseline	2.18±0.83			2.44±0.71			0.372*		
1st month	1.94±0.67			2.42±0.68			0.173*		
3rd month	1.98±0.74			2.40±0.67			0.171*		
p		0.218**			0.116**				
Δ1		−0.25	−2.13-0.88		0	−0.25-0.13	0.137***		
Δ2		−0.25	−2.13-1.25		−0.07	−0.38-0.13	0.412***		
Appearance									
Baseline	2.67±0.78			2.66±0.44			0.986*		
1st month	2.59±0.62			2.50±0.39			0.639*		
3rd month	2.75±0.78			2.51±0.39			0.286*		
p		0.267**			0.133**				
Δ1		0	−0.86-0.71		0	−1.29-0	0.806***		
Δ2		0	−0.43-0.71		0	−1.29-0.38	0.217***		
Symptoms									
Baseline	2.33±0.66			2.41±0.49			0.711*		
1st month	2.24±0.76			2.29±0.53			0.826*		
3rd month	2.24±0.80			2.26±0.53			0.916*		
p		0.382**			0.122**				
Δ1		0	−0.80-0.40		0	−1.20-0	0.935***		
Δ2		0	−0.80-0.80		0	−1.20-0	0.935***		
Emotional									
Baseline	1.91±0.85			1.85±0.57			0.825*		
1st month	1.83±0.93			1.74±0.37			0.472*		
3rd month	1.83±0.93			1.71±0.36			0.403*		
p		0.386**			0.122**				
Δ1		0	−0.83-0.50		0	−1.40-0	0.902***		
Δ2		0	−0.83-0.50		0	−1.40-0	0.486***		
Overall QoL									
Baseline	5.60±1.63			5.33±1.54			0.650*		
1st month	6.53±1.72			6.33±1.39			0.730*	0.10	−0.60, 0.80
3rd month	6.46±1.64			6.46±1.30			1.000*	0.00	−0.70, 0.70
p		**0.002****			0.062**				
Δ1		1	0-3		0	0-8	0.512***		
Δ2		1	−1-2		1	0-8	0.744***		

LYMQOL: Lymphedema quality of life questionnaire; TECAR: Transfer energy capacitive and resistive; SD: Standard deviation; CI: Confidence interval; * Student's t-test; ** Repeated measures ANOVA (with Greenhouse-Geisser correction where sphericity was violated; Bonferroni adjustment applied for post hoc comparisons); *** Mann-Whitney U test; Δ1: Baseline-first month; Δ2: Baseline-third month. Significance level p<0.05, Significant p-values shown in bold.

Quality of life

Based on the LYMQOL-Leg questionnaire, no statistically significant changes were observed in either group across the functional, appearance, symptom, or emotional subdomains over time (p>0.05 for all comparisons). Post hoc analyses indicated that overall QoL significantly improved in the TECAR group at both one and three months compared to baseline (p=0.002 and p=0.013, respectively); however, no difference was noted between one- and three-month scores (p=1.000). No significant change occurred in the control group (p=0.062). There was no difference in between-group comparisons (Table 6).

DISCUSSION

Lipedema is a chronic adipose tissue disorder that remains difficult to manage due to its resistance to conventional treatments. Conservative approaches such as compression garments, manual lymphatic drainage, and exercise may offer partial symptom relief but are often insufficient for sustained long-term control.[2,5] Given its physiological effects, TECAR therapy may be effective in alleviating lipedema-related symptoms. In this context, our randomized controlled study demonstrated that the addition of TECAR therapy to standard treatment led to significantly greater improvements in key clinical outcomes, such as limb circumference, pain intensity, and overall QoL, compared to standard treatment alone. Although TECAR therapy has shown promising results in various musculoskeletal and neurological disorders, as well as in lymphedema, to our knowledge, no previous randomized study has evaluated its efficacy in lipedema.[11-15,18]

The pathophysiology of lipedema involves a complex interplay of hormonal imbalances, microvascular and lymphatic dysfunction, immune activation, and extracellular matrix remodeling. Vascular fragility, increased capillary permeability, and lymphatic insufficiency lead to persistent interstitial fluid retention and chronic edema, setting the stage for progressive tissue alterations.[4,6,7] These processes are further amplified by extracellular matrix stiffening and angiogenesis, creating a hypoxic, inflamed environment that underlies hallmark symptoms such as pain, heaviness, and impaired mobility.[2,4,7,28] Given these pathophysiological mechanisms, TECAR therapy represents a biologically plausible and clinically promising intervention for lipedema. By delivering high-frequency electromagnetic energy via capacitive and resistive electrodes, TECAR exerts both thermal and nonthermal effects that enhance microcirculation, stimulate lymphatic drainage, and promote tissue remodeling.[11,12,29,30] These actions are believed to underlie its ability to relieve common symptoms such as pain and soft tissue stiffness.

Studies exploring TECAR therapy in diverse musculoskeletal pathologies have indicated that TECAR therapy has been applied in regimens ranging from 6 to 24 sessions over two to six weeks.[31] The same systematic review showed that the frequencies employed in most of the studies ranged between 440 and 600 KHz. In their preliminary study on lipedema, Cau et al.[13] applied TECAR therapy to the groin, popliteal fossa, and sole (15 min each, total 45 of min) using frequencies of 0.8 to 1.2 MHz for both extremities. They applied six daily 90-min sessions for four weeks. In a prospective, randomized controlled trial comparing the effectiveness of TECAR therapy to that of laser therapy in patients with low back pain, each patient was treated five times a week for a total of 10 sessions with TECAR therapy in a frequency range between 0.45 and 0.60 MHz.[32] Our protocol of six sessions over three weeks with a frequency of 500 kHz aligns with the lower end of this spectrum.

In our study, a significant reduction in pain intensity was observed in the TECAR group at one month after treatment, indicating a short-term analgesic benefit. However, post hoc analysis showed that this reduction was not statistically significant at the three-month follow-up compared to baseline ($p=0.052$). The control group showed no significant changes in pain levels throughout the study. The exact mechanisms of pain in lipedema remain uncertain but may involve mechanical compression of nerve endings from adipose hypertrophy, localized inflammation, and central sensitization, a process involving amplified pain signaling in the central nervous system.[5] The analgesic effects of TECAR analgesic effects are likely multifactorial, involving improved tissue oxygenation, lymphatic clearance, modulation of inflammatory mediators, and neuromodulation of nociceptive pathways.[13,30,33,34] These mechanisms may account for the early pain relief observed in our study. However, they may wane over time once the active stimulus is withdrawn and may not translate into long-term relief unless repeated or ongoing therapy is provided. Our findings are consistent with previous research demonstrating the efficacy of TECAR in reducing pain in musculoskeletal and soft tissue disorders.[11,12,14,15] However, further studies are needed to assess its long-term effectiveness in lipedema.

An alternative explanation for the early but not sustained pain reduction observed in the TECAR group is the influence of nonspecific effects. The expectation of benefit and the therapeutic setting itself can elicit a placebo response, particularly for pain outcomes, which are highly subjective and sensitive to patient perception. Additionally, regression to the mean or natural symptom fluctuation could partly account for short-term improvements. It should also be considered that all participants received concurrent compression

therapy and exercise, which are known to alleviate discomfort and improve function in lipedema. Because the control group was also exposed to compression, this standard therapy may have mitigated between-group differences over time, particularly at the three-month mark. Nevertheless, three factors suggest that the observed early analgesia in the TECAR group was not entirely attributable to nonspecific or concurrent treatment effects. First, pain improvements peaked temporally during the active treatment window, aligning with TECAR's proposed physiological mechanisms. Second, between-group comparisons remained statistically significant for pain change from baseline to three months, despite the nonsignificance of within-group analyses at that time point. Finally, the pain trajectory paralleled early circumference reductions, which lends biological plausibility that a treatment-specific effect contributed to the analgesic response. Future trials including sham-controlled TECAR arms or varying maintenance schedules are essential to disentangle these effects and clarify the durability of analgesia.

Beyond its analgesic effects, TECAR therapy was associated with greater reductions in limb circumference compared to standard care alone. Although both groups showed significant decreases in mid-thigh and pretibial measurements over time, a significant reduction in supramalleolar circumference occurred only in the TECAR group. At the one-month follow-up, reductions were significantly greater in all measured regions in the TECAR group, and this advantage persisted at three months in the supramalleolar area, where lipedema-related fluid accumulation is often most prominent. This observation is physiologically plausible, as the ankle region is a gravity-dependent site where venous and lymphatic stasis tends to be most pronounced in lipedema. The combination of TECAR therapy and compression may have produced a sustained improvement in microcirculation and lymphatic outflow at this distal level, leading to longer-lasting volume reduction. By contrast, more proximal regions of the limb are often affected by a higher proportion of fibroadipose tissue and structural changes, which respond more slowly to short-term interventions. Moreover, compression garments exert their greatest effective pressure at the ankle, which may have helped maintain reductions in this area. Taken together, these findings suggest that TECAR therapy may be effective in targeting distal edema components of lipedema, while proximal adipose-dominant changes may require longer or more intensive treatment protocols.

Notably, these regional improvements were observed despite stable BMI, suggesting local effects independent of systemic weight change. Although higher BMI contributes to the severity of lipedema, our findings suggest that TECAR therapy remains effective across BMI categories <35. The persistence of supramalleolar circumference reduction and early pain relief irrespective of BMI implies that treatment efficacy is more dependent on local microcirculatory changes than on overall adiposity. This supports the hypothesis that TECAR's therapeutic effects are primarily local, likely mediated through improved lymphatic drainage and microcirculatory function.[13] While edema reduction appears to be the most immediate mechanism, the possibility of localized tissue remodeling, such as decreased fibrotic resistance or enhanced adipocyte pliability, cannot be excluded.[13,15] Future studies incorporating imaging modalities, such as ultrasound or magnetic resonance imaging, could help clarify whether the persistent distal effect is primarily attributable to fluid shifts or to modifications in tissue composition. In addition, larger trials including patients with BMI ≥35 are warranted to confirm whether obesity alters treatment responsiveness.

Recent international consensus guidelines highlight microangiopathy, chronic low-grade inflammation, and progressive fibrotic remodeling as central drivers of lipedema.[1,3,35] These insights provide a framework for interpreting our findings. TECAR's proposed mechanisms (microcirculatory enhancement, anti-inflammatory effects, and fibrotic tissue softening) directly address these disease processes. The sustained supramalleolar reduction may reflect improved distal fluid clearance, while early pain relief aligns with anti-inflammatory and perfusion-related effects. Although proximal and long-term changes were limited, our results are consistent with the consensus view that comprehensive, multimodal care is required and that energy-based physical modalities may serve as adjunctive options.

Patients with lipedema may experience reduced lower extremity function due to pain, swelling, and increased fat tissue, which can limit mobility and daily activities.[36,37] In our study, although an improvement trend in lower extremity function

evaluated by LEFS scores was observed in the TECAR group, this improvement was not statistically significant (p=0.058). One possible explanation is the relatively preserved baseline functional status of participants. Given that all participants had Stage II, type 3 lipedema, and that between-group differences were not influenced by heterogeneity in lipedema type, the combination of fibrotic changes and mechanical overload likely limited proximal circumference reduction and durability of pain relief. This helps explain why improvements in LEFS scores were modest, as functional gains depend largely on reduced bulk and pain in the thighs and calves, where disease burden is greatest.

Despite reductions in pain and limb circumference, our study did not reveal statistically significant changes in specific LYMQOL subdomains, including function, appearance, mood, or symptoms. Only the overall QoL score showed a statistically significant improvement. Importantly, the LYMQOL includes a global QoL score rated on a scale from 0 to 10, which is assessed independently from the subdomain scores. Thus, this improvement likely reflects a general subjective perception of well-being or symptomatic relief, rather than discrete, measurable gains in psychosocial or functional domains. This distinction underscores the complexity of evaluating QoL in individuals with lipedema, as physical symptom relief does not necessarily translate into improvements in emotional well-being, body image, or social participation.[5,38]

Baseline comorbidities, including hypertension, hypothyroidism, type 2 diabetes mellitus, and osteoarthritis, were similarly distributed across groups, reducing the likelihood that systemic conditions confounded the observed outcomes. Nevertheless, as the study was not powered to detect imbalances in relatively rare comorbidities, such as coronary artery disease, a small residual risk of confounding cannot be excluded.

This study had certain limitations. Our sample size was relatively small and powered only to detect medium-sized differences in the primary outcome (VAS pain at one month). This raises the possibility of type 2 error, particularly for secondary outcomes such as LEFS and LYMQOL subdomains, where clinically meaningful but smaller effects may have gone undetected. Overall, the relatively small sample size restricted the ability to detect smaller but clinically relevant effects and limited the generalizability of our findings. While the study was powered to identify significant improvements in pain at one month and sustained supramalleolar circumference reduction at three months, larger trials are required to validate these outcomes, explore subtler treatment effects, and evaluate durability across diverse patient populations. Nonetheless, our findings provide valuable preliminary evidence and a foundation for future multicenter studies. We acknowledge that we did not perform subgroup analyses to evaluate whether treatment response differed by BMI category. The follow-up duration was limited to three months, which may not be sufficient to fully assess the long-term sustainability of TECAR's clinical effects in individuals with lipedema. Additionally, no imaging-based assessments (e.g., ultrasound or magnetic resonance imaging) were employed, which restricted the ability to distinguish between reductions in interstitial fluid and potential changes in subcutaneous tissue composition. Another limitation of this study was the absence of standardized assessment of psychological status at baseline. Given the high prevalence of depression, anxiety, and body image distress in lipedema, future studies should incorporate validated psychological screening tools to better account for the influence of psychosocial factors on pain and QoL outcomes.

To the best of our knowledge, this is the first randomized controlled study to investigate the effects of TECAR therapy in individuals with Stage II, type 3 lipedema. The results suggest that TECAR, when added to standard conservative care, may provide short-term pain relief and a sustained reduction in supramalleolar circumference. However, these benefits were localized, partially transient and observed in a small, homogenous sample of female patients. While these preliminary findings support TECAR as a potential adjunctive therapy within comprehensive management, larger and more diverse trials are required to confirm its role and to determine durability, functional impact, and its other effects.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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