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Original Article

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Assessing the Effects of Electrical Muscle Stimulation and Resistance Training on Regulation of HbA1c and Plasma Glucose in Individuals with Type 2 Diabetes Mellitus: An Experimental Study

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Abstract

Background: Type 2 diabetes mellitus (T2DM) is a common metabolic condition that places a major health and financial burden on individuals and healthcare systems worldwide. Maintaining good glycemic control, particularly through measures such as HbA1c and blood glucose levels, is essential for reducing the risk of long-term complications. Although resistance training is widely recommended for diabetes management, it may not be suitable for people with limited mobility or multiple comorbidities. This study compared the effects of Electrical Muscle Stimulation (EMS) and Resistance Training (RT) on glycemic outcomes in individuals with T2DM.

Methods: Sixty-six participants with T2DM were randomly allocated to one of three groups: EMS, RT, or control, with 22 participants in each group. The EMS group received 30-minute stimulation sessions three times per week for 12 weeks. The RT group completed supervised progressive resistance exercises targeting the major lower-limb muscles on the same schedule. The control group received education on diet, exercise, and blood glucose management. HbA1c, fasting blood glucose, and postprandial glucose were measured at baseline, after 12 weeks, and again at 3-month follow-up.

Results: Both intervention groups showed significant improvements in glycemic control compared with the control group. HbA1c fell from 8.77 to 7.59 in the EMS group and from 8.73 to 8.05 in the RT group, while it increased from 8.91 to 9.41 in controls. Fasting and postprandial glucose levels also improved significantly in both intervention groups.

Conclusion: Both EMS and RT were effective, with EMS showing stronger and more sustained benefits in this study.

Keywords: Blood glucose, Diabetes mellitus, Electrical stimulation therapy, Glycated hemoglobin A (HbA1c), Glycemic control, Resistance training

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Introduction

Type 2 Diabetes Mellitus (T2DM) is a chronic metabolic disorder characterized by insulin resistance, impaired insulin secretion, and chronic hyperglycemia, posing a significant global health burden (1). According to the International Diabetes Federation, T2DM is expected to affect over 700 million people worldwide by 2045 (2). Among the various treatment modalities, lifestyle interventions such as physical exercise have been extensively studied for their role in managing glycemic control. Traditionally, Resistance Training (RT) has been a cornerstone of exercise therapy for T2DM due to its benefits in improving insulin sensitivity and muscle strength (3). However, Electrical Muscle Stimulation (EMS), an emerging therapeutic technique, has also garnered attention for its potential to modulate glucose metabolism (4).

RT has been shown to enhance glycemic control in individuals with T2DM by increasing muscle mass, improving insulin sensitivity, and promoting glucose uptake by skeletal muscle (5). Several studies have highlighted that RT improves long-term blood glucose regulation by enhancing insulin sensitivity and reducing the risk of cardiovascular complications (6). The mechanistic effects of RT on muscle glucose uptake are well-documented (7,8).

Conversely, EMS involves the application of electrical impulses to stimulate muscle contractions, which theoretically mimics the effects of voluntary muscle activity, albeit at a lower intensity (9). EMS has been used in clinical rehabilitation and has shown promise in improving muscle strength and endurance in patients with neuromuscular disorders (10). Recent studies have also indicated that EMS may improve insulin sensitivity and glycemic control, suggesting it as a potential adjunctive therapy for individuals with T2DM (11). The mechanism behind EMS's effects on glucose regulation is still under exploration, with hypotheses pointing to increased glucose uptake in muscle tissue due to enhanced muscle contractions and improved blood flow during EMS interventions (12).

Given previous evidence indicating that RT and EMS improve insulin sensitivity and glucose regulation, it was hypothesised that both interventions would lead to significant reductions in glycated haemoglobin (HbA1c), Fasting Blood Sugar (FBS), and Post Prandial Glucose (PPG) relative to the control group. It was anticipated that EMS would produce greater and more sustained improvements than RT, owing to its preferential recruitment of fast-twitch muscle fibres and its capacity to stimulate muscle metabolism independently of voluntary effort.

The existing literature on RT and EMS has expanded significantly; however, direct comparative trials evaluating their specific impacts on glycemic control in individuals with Type 2 Diabetes Mellitus (T2DM) are limited. This study examines the distinct impacts of EMS and RT on critical glycemic indicators (HbA1c, FBS, and PPG) in individuals with T2DM, thereby addressing an existing knowledge gap. This study is clinically significant as it offers insights into possible alternative or complementary therapeutic approaches for managing blood glucose levels. These strategies are especially beneficial for patients encountering obstacles to participating in conventional exercise, such as comorbidities, mobility limitations, or restricted access to organised training facilities. This study investigates the relative efficacy of EMS and RT in a controlled clinical setting to provide evidence that informs clinical decision-making and guides individualised management strategies for T2DM.

Materials and Methods

Study setting and design

This study was conducted at the Department of Physiotherapy, School of Healthcare and Allied Sciences, GD Goenka University (October 2023–September 2024). The study was registered with the Clinical Trials Registry–India (CTRI/2023/09/057825) and approved by the Institutional Ethical Committee (WWET/2023/IEC-AP/03).

Participants

A total of 66 participants (aged 45–65 years) with clinically diagnosed T2DM were recruited through convenience sampling. After screening, they were randomized equally into three groups (n=22 per group): EMS group (Electrical Muscle Stimulation), RT group (Resistance Training), Control group (Educational/Standard Care). Randomization was performed using a chit system by an independent researcher not involved in recruitment or intervention delivery.

Eligibility criteria

Inclusion criteria: T2DM diagnosis; fasting blood glucose 100–250 *mg/dl*; on oral hypoglycemic agents but not insulin; low activity level by International Physical Activity Questionnaire (IPAQ) (13); willing to participate. On the other hand, exclusion criteria included type 1 diabetes mellitus, insulin use, pregnancy, physical activity levels above the IPAQ "low" category, uncontrolled or fluctuating blood pressure or glucose, recent myocardial infarction (within 6 months), unstable angina, uncontrolled arrhythmias, severe orthopaedic or musculoskeletal conditions limiting participation in exercise, untreated thyroid disorders, active systemic or skin infections (which could interfere with EMS application), presence of metal implants or pacemakers, recent major surgery, or substance abuse (alcohol, smoking, or drugs affecting the neuromuscular system) (Figures 1-3).

EMS procedure: A multi-channel (8 channels) electrical muscle stimulator from Johri Digital (model no. TR841) was employed for the EMS group to administer stimulation to six muscles (bilateral glutei maximus, hamstrings, and quadriceps) during a single 30-*min* session, with three sessions per week over a 12-week period. Following a standard clinical protocol, a Russian current at a frequency of 2500 *Hz* and motor-level intensity was applied. The stimulation protocol included 10 *s* of stimulation followed by a 50-*s* rest interval, with two muscles being stimulated simultaneously for 10-*min* allotments per muscle pair (14,15). Electrode placement during EMS targeting the bilateral quadriceps, hamstrings, and gluteus

Figure 1.

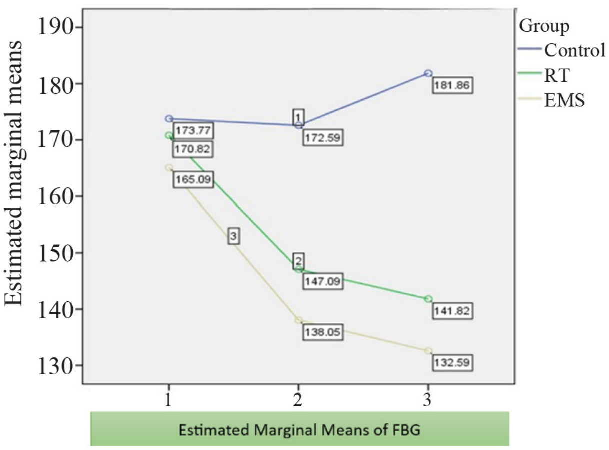

Figure 2.

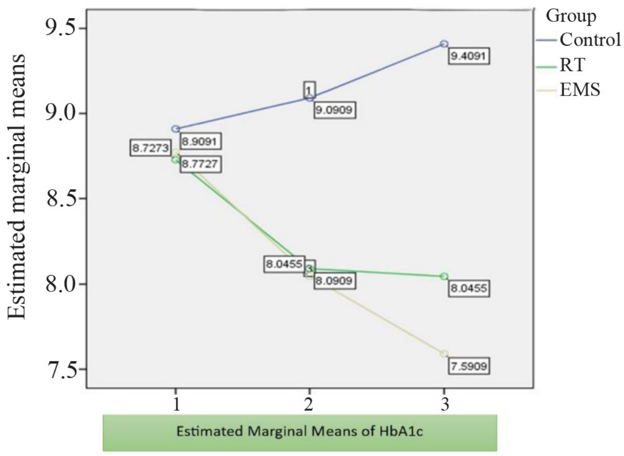

Figure 3.

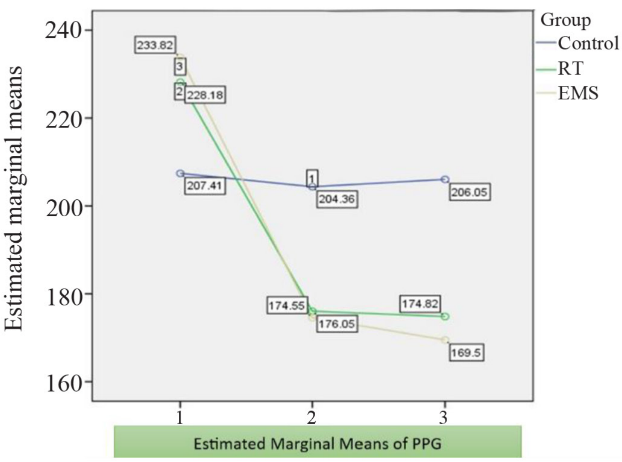

Figure 1, 2, 3. Shows the mean of FBG, HbA1c, & PPG respectively of all the three groups at different points of time interval.

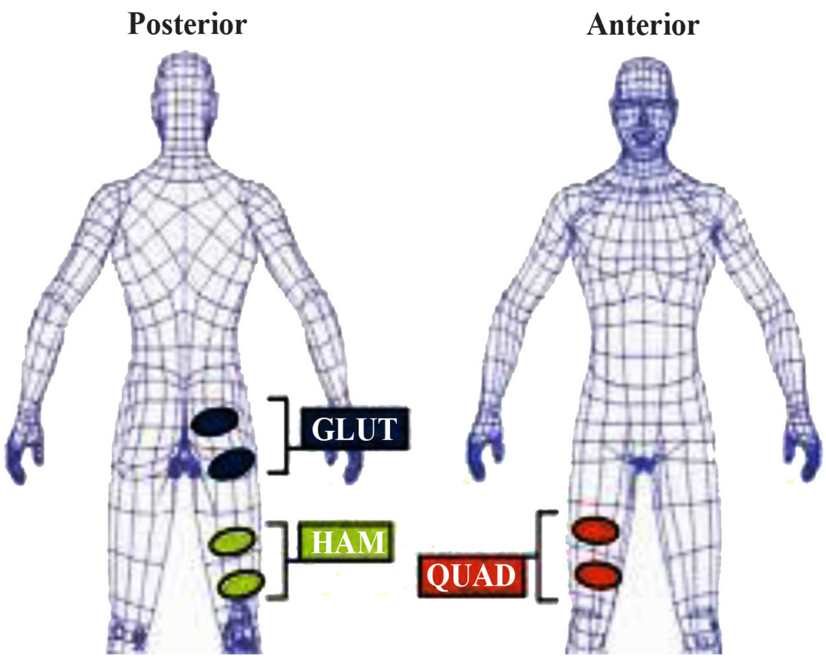

Figure 4. Electrode placement for EMS on bilateral quadriceps, hamstrings, and gluteus maximus.

maximus muscles is shown in figure 4.

RT procedure: A supervised Progressive Resistance Training (PRT) protocol was implemented for the exercise group, targeting the hip extensors, hip flexors, knee extensors, knee flexors, elbow flexors, shoulder flexors, and plantar flexors bilaterally. Each participant began with a 10-*min* warm-up, consisting of gentle stretching for all four limbs. This was followed by resistance exercises, consisting of up to two sets of 10 repetitions per muscle group, using a resistance equivalent to 3 Repetition Maximum (RM) in each session. The training sessions were conducted three alternate days per week for a duration of 12 weeks. The 1RM (One Repetition Maximum) was calculated using the formula:

1RM = weight lifted / 1.0278 - (repetitions×0.0278)

as outlined by Brzycki, 1993 (16). When participants were able to perform 20 repetitions with ease, an additional 0.5 *kg* of resistance was added to the training load (17).

Participants in the control group received educational interventions on dietary management, exercise, and glycemic control strategies. They were encouraged to increase their leisure physical activity and participate in low-to-moderate intensity exercises, such as walking, household chores, and cycling, for 20-30 *min*.

Data analysis was performed using the SPSS software, version 25.0 (IBM, USA). Descriptive statistics were applied to calculate the mean and standard deviation of the demographic, anthropometric profiles, and outcome measures of the participants. The Shapiro-Wilk test was used to assess the normality of the data. Group differences were analysed using repeated measures ANOVA, and corresponding p-values and F-values were computed. Post-hoc tests were conducted to examine specific group comparisons, with statistical significance set at $p<0.016$.

Outcome measures: Glycated haemoglobin (HbA1c) was the primary outcome measures while secondary outcomes were FBS and PPG. Assessments were conducted at baseline (pre-intervention), post-intervention (post 12 weeks of intervention), follow-up (3 months after intervention completion).

Results

There were total of 66 participants, among which 22 participants were recruited to all three groups, namely EMS, RT & Control groups. Descriptive statistics were computed as mean±standard deviation (SD), at 95% Confidence Intervals (CI) calculated for all continuous variables.

Sample size calculation was done by using the formula (18).

$$n = \frac{[z\alpha/2 + z\beta]^2 \times 2\sigma^2}{\delta^2}$$

Where:

σ of HbA1c=0.7, Significance level 5%, Power=80%, Hypothesis=two tail, zα=1.96, zβ=0.84.19

(n = required sample size per group

$Z_\alpha/2$=critical value of the standard normal distribution corresponding to the desired significance level (α)

Z_β= critical value of the standard normal distribution corresponding to the desired power (1−β)

σ = standard deviation of the outcome variable

δ= minimum detectable difference between the two group means)

Table 1 (A) and 1(B) are showing the descriptive data of the study samples. Table 2 provides the descriptive statistics for HbA1c, PPG, and FBS. The mean±SD of HbA1c at baseline for the Control, RT, and EMS groups were 8.91±1.34, 8.73±1.20, and 8.77±1.23, respectively. At the end of the intervention, the values were 9.09±1.19, 8.09±1.11, and 8.05±1.40, respectively. For follow-up after the intervention, the values were 9.41±1.37, 8.05±1.25, and 7.59±1.33, respectively. The mean±standard deviation of PPG at baseline for the Control, RT, and EMS groups were 207.41±21.13, 228.18±55.28, and 233.82±65.33, respectively. At the end of

Table 1A). Mean±SD of age and height in all three groups

Characteristics (Mean ± SD)	EMS group (n=22) (95%CI)	RT group (n=22) (95%CI)	Control group (n=22) (95%CI)
Age (years)	53±3.7	52±4.84	49.77±6.75
Height (*cm*)	167.60±7.52	168.04±6.17	165.63±6.82

Table 1B). Mean±SD of weight in all three groups at 3 different point of time

Charac-teristics (M±SD)	EMS group (n=22) (95% CI)			RT group (n=22) (95% CI)			Control group (n=22) (95% CI)		
	Baseline	Post intervention	Follow-up	Baseline	Post intervention	Follow-up	Baseline	Post intervention	Follow-up
Weight (*kg*)	72.82±11.88	70.28±12.39	69.93±12.47	73.60±8.69	71.47±9.24	70.25±9.52	79.63±10.90	80.17±10.83	80.60±10.47

Table 2. Mean±SD of HbA1c, Postprandial Glucose (PPG) and Fasting Blood Sugar (FBS)

Time Point	Groups	HbA1c (Mean±SD)	PPG (Mean±SD)	FBS (Mean±SD)
Baseline	Control	8.91±1.34	207.41±21.13	173.77±30.91
	RT	8.73±1.20	228.18±55.28	170.82±43.62
	EMS	8.77±1.23	233.82±65.33	165.09±40.23
Post intervention	Control	9.09±1.19	204.36±27.82	172.59±25.99
	RT	8.09±1.11	176.05±20.27	147.09±32.27
	EMS	8.05±1.40	174.55±23.45	138.05±26.04
Follow-up	Control	9.41±1.37	206.05±26.09	181.86±23.38
	RT	8.05±1.25	174.82±19.39	141.82±25.79
	EMS	7.59±1.33	169.50±19.19	132.59±21.90

Electrical Muscle Stimulation (EMS); Resistance Training (RT).

Table 3. Statistical Results for HbA1c, PPG, and FBS

Effect	Test	F-value	p-value	Partial Eta Squared (η²)	Interpretation
Time (HbA1c)	Repeated Measures ANOVA	15.593	<0.001	0.198	Significant changes in HbA1c over time
Group×Time (HbA1c)	Interaction Effect	16.299	<0.001	0.341	Significant group differences over time
Time (PPG)	Repeated Measures ANOVA	50.133	<0.001	0.443	Significant reduction in PPG over time
Group×Time (PPG)	Interaction Effect	11.460	<0.001	0.267	Significant group differences over time
Time (FBS)	Repeated Measures ANOVA	25.069	<0.001	0.285	Significant reduction in FBS over time
Group×Time (FBS)	Interaction Effect	10.500	<0.001	0.250	Significant group differences over time

Effect sizes were interpreted using Cohen's conventional benchmarks: small (η^2=0.01), medium (η^2=0.06), and large ($\eta^2 \geq 0.14$), Post Prandial Glucose (PPG); Fasting Blood Sugar (FBS).

the intervention, the values were 204.36±27.82, 176.05±20.27, and 174.55±23.45, respectively. During the follow-up after the intervention, the readings were 206.05±26.09, 174.82±19.39, and 169.50±19.19, respectively. The mean±SD of FBS for the pre-intervention period in the Control, RT, and EMS groups were 173.77±30.91, 170.82±43.62, and 165.09±40.23, respectively. For the post-12 weeks stage, the values were 172.59±25.99, 147.09±32.27, and 138.05±26.04, respectively. For the follow-up after intervention, the values were 181.86±23.38, 141.82±25.79, and 132.59±21.90, respectively.

Table 3 presents the statistical profile of dependent and independent variables along with their outcome measures, demonstrating a p-value of less than 0.001. The change in HbA1c values is significant, evidenced by an intra-group comparison yielding an F-value of 15.593 and a η^2 value of 0.198, as well as an inter-group comparison with an F-value of 16.299 and a η^2 value of 0.341 over time. Significant changes in PPG were observed, evidenced by an intra-group comparison yielding an F-value of 50.133 and a η^2 value of 0.443, as well as an inter-group comparison with an F-value of 11.460 and a η^2 value of 0.267 over the specified time period. A notable change has been observed in FBS values during intra-group comparison, with an F-value of 25.069 and a η^2 value of 0.285. Similarly, for inter-group comparison, the F-value is 10.500 and the η^2 value is 0.250 over the specified period.

Table 4 shows the statistical profile for inter-group comparisons over the independent variable like

Table 4. Pairwise Comparisons for HbA1c

Groups compared	Mean difference	p-value	Significance
Control *vs.* RT	0.848	0.023*	Significant
Control *vs.* EMS	1.000	0.008**	Significant
RT *vs.* EMS	0.152	0.678	Not Significant

*p<0.05, **p<0.01, Electrical Muscle Stimulation (EMS); Resistance Training (RT).

Table 5. Pair wise comparisons of PPG

Groups	Mean difference	Std. error	p-value	95%CI
Control *vs.* RT	12.924	8.372	0.383	-7.667 to 33.516
Control *vs.* EMS	13.318	8.372	0.350	-7.273 to 33.909
RT *vs.* EMS	0.394	8.372	1.000	-20.197 to 20.985

Post Prandial Glucose (PPG); Electrical Muscle Stimulation (EMS); Resistance Training (RT).

Table 6. Pair wise comparisons of FBS

Groups	Mean Difference	Std. Error	p-value	95%CI
Control *vs.* RT	22.833*	8.372	0.025*	2.242 to 43.425
Control *vs.* EMS	30.833*	8.372	0.001**	10.242 to 51.425
RT *vs.* EMS	8.000	8.372	1.000	-12.591 to 28.591

*p<0.05, **p<0.01, Fasting Blood Sugar (FBS).

HbA1c. Only the control *vs.* RT group and control versus EMS group holds a significant difference. Table 5 shows no statistically significant differences were observed between the groups ($p<0.05$). Table 6 shows significant differences exist between Control *vs.* RT and Control *vs.* EMS groups ($p<0.05$).

Discussion

The current study showed that among those with Type 2 Diabetes Mellitus (T2DM), EMS and RT both significantly improved glycemic control. Significantly, at the three-month follow-up, EMS produced longer-lasting benefits, suggesting that it might be a good substitute for RT for patients who are unable to perform conventional exercises. This experiment adds new data to exercise-based therapies for metabolic management in type 2 diabetes by directly comparing RT and EMS. The improvements that have been seen are consistent with physiological processes that have been proven. The main mechanisms by which EMS and RT increase skeletal muscle glucose uptake are AMPK activation and insulin-independent GLUT-4 translocation (20). Furthermore, EMS activates the AMPK–PGC-1α signalling pathway, enhancing mitochondrial biogenesis and oxidative metabolism mechanisms that likely underlie its sustained effects on diabetic management (21). These results align with research demonstrating that neuromuscular electrical stimulation can replicate the metabolic changes commonly observed during voluntary exercise.

Irisin is a myokine released during muscular contraction that may perhaps be a factor in this research findings. Research indicates that as compared to aerobic exercise, EMS can considerably increase the levels of circulating irisin (22,23). Irisin activates the ERK/Nrf2/HO-1 pathway, which improves insulin sensitivity and lowers oxidative stress (24). The improved glycemic control in the EMS group may indicate alterations in the irisin-oxidative stress axis. Irisin has demonstrated the ability to safeguard pancreatic β-cells from oxidative injury by activating the Txnip/Stat3/Trx2 pathway (25). Furthermore, oxidative stress is a recognised modulator of insulin resistance and β-cell dysfunction (26). However, this is still conjectural because the current study lacks direct biomarker measurements.

In T2DM, inflammation is another important route. Both RT and EMS have been linked to decreased levels of pro-inflammatory cytokines such IL-6 and TNF-α, which improves the action of insulin.[27,28] Future mechanistic research should examine the possible participation of inflammatory mediators, even if they were not evaluated in this investigation.

Clinically, these results support the idea that scheduled exercise is essential to managing type 2 diabetes. They also show that EMS can be a useful substitute for patients who have comorbidities, limited mobility, or poor participation in traditional exercise regimens. Because EMS can cause contraction-driven glucose uptake without the need for deliberate effort, it is particularly useful for people who cannot tolerate RT. Additionally, EMS devices may be used in rehabilitation or home-based settings, increasing access to diabetic treatments that don't include the use of pharmaceuticals.

When combined, present findings support earlier research showing resistance training enhances glycemic control in type 2 diabetes (T2DM) (6,17). They also add to this body of literature by offering one of the first direct head-to-head comparisons between resistance training and electrical muscle stimulation. It was shown that EMS not only improves HbA1c, fasting, and postprandial glucose, but also has greater and longer-lasting effects than RT, as shown at 3-month follow-up, in contrast to previous EMS-only trials (29,30). This study closes a significant vacuum in the literature by highlighting EMS as a therapeutically beneficial substitute for patients unable to engage in traditional resistance training. This study enriches the field by establishing the relative efficacy of these two modalities in a single experiment and validates previous reports of exercise benefits by demonstrating that EMS can equal or exceed the documented advantages of RT.

Limitations

Convenience sampling approach may limit generalizability. Mechanistic interpretation is limited by the lack of molecular indicators such as irisin, oxidative stress indices, or inflammatory cytokines. Additionally, the follow-up period was somewhat brief, making it unable to draw conclusions on long-term sustainability. Results may have been impacted by the loose management of dietary and medication adherence variations. Larger cohorts, longer follow-up periods, and biomarker analyses should all be incorporated into future studies in order to elucidate the processes behind the metabolic advantages generated by EMS.

Conclusion

RT and EMS both helped people with type 2 diabetes improve their glycemic control, but EMS's benefits were stronger and lasted longer. This study adds to the body of information by directly comparing both therapies and raises the possibility that EMS could be a useful, clinically relevant substitute for traditional resistance training in the treatment of diabetes.

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Disclaimer

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Conflict of Interest

There are no conflicts of interest to report.

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