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ORIGINAL RESEARCH

The Influence of Skin Parameters and Body Composition on the Tolerance of Pain Stimulus Generated During Electrical Muscle Stimulation (EMS) in Women - Pilot Study

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Purpose: This pilot study aims to explore how skin parameters and body composition impact the tolerance to EMS (Electrical Muscle Stimulation) stimuli in women, particularly focusing on pain tolerance in response to varying intensities of EMS. This research seeks to understand what is essential for optimizing EMS applications.

Patients and Methods: The study involved 16 females (age 35.9 ± 12.3). Body composition and anthropometric measurements were taken, including BMI (Body Mass Index), weight percentage, WHtR (Waist to Height Ratio), WHR (Waist-Hip Ratio), and Bioelectrical Impedance Analysis. High-frequency ultrasound scans were conducted to assess skin parameters. The EMS stimulation was performed using an Evolvex (InMode, Israel), with applicators placed around the abdomen and intensity adjusted according to patient tolerance, recorded at the pain threshold.

Results: The maximum tolerated EMS stimulus varied from 12V to 55V, with a median of 33V. Body weight showed a strong positive correlation (R=0.76, p<0.001) and hip circumference (R=0.66, p<0.001) with EMS intensity. Body fat mass (R=0.61, p=0.012) and visceral fat area (R=0.55, p=0.029) were positively correlated with EMS intensity. However, no significant correlations were observed between EMS tolerance and muscle tissue parameters or total body water content. The study also found that skin structure parameters showed no significant impact on EMS tolerance.

Conclusion: The study reveals that women's tolerance to EMS stimuli is influenced by various factors. Anthropometric parameters like hip circumference, body weight, skinfold, and BMI are strongly correlated with EMS tolerance. Body composition factors, particularly adipose tissue characteristics such as body fat mass and percentage, also significantly impact EMS intensity requirements, with no notable correlation to muscle tissue or water content. However, variations in skin structure, including thickness and density, do not significantly affect EMS tolerance. These insights are crucial for tailoring personalized EMS therapy to enhance effectiveness and comfort in both aesthetic and rehabilitative applications.

Keywords: EMS, body composition, BIA, high-frequency ultrasound

Introduction

Electrical Muscle Stimulation (EMS) is increasingly being recognized for its diverse applications in rehabilitation, athletic training, and pain management. This pilot study specifically aims to explore the impact of skin parameters and body composition on the tolerance of EMS stimuli in women, with a particular focus on pain tolerance in response to different intensities of EMS.

EMS uses electrical impulses to induce muscle contractions, a method that has seen widespread application and research.[1–5] The effectiveness and comfort level of EMS are heavily influenced by the intensity of the electrical stimulus, which varies in its pain-inducing potential. The perception of pain, especially in response to electrical stimulation, is highly subjective and can be influenced by several physiological and psychological factors.[6,7]

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In women, these factors are further compounded by hormonal variations, skin characteristics, and differences in body composition. Studies have shown that hormonal fluctuations can affect pain perception and tolerance.[8,9] Additionally, the distinct properties of women's skin, such as hydration, thickness, and elasticity, are known to influence electrical conductivity, potentially altering the sensation of pain induced by EMS.[10] The higher body fat percentage in women also affects the pathway and distribution of the electrical current, which can modify the intensity of the pain stimulus experienced during EMS.[11]

This study will critically examine how these variables interact to influence pain tolerance in response to varying EMS intensities in women. Understanding these relationships is key to optimizing EMS applications, ensuring they are both effective and tolerable. The variability in pain tolerance is a significant factor that can affect the acceptance and efficacy of EMS in therapeutic and fitness settings.

Recent research has highlighted the importance of personalizing medical and fitness interventions, considering individual physiological differences for optimal outcomes.[12] In the case of EMS, personalization becomes crucial given the diverse responses to pain stimuli. Differences in skin conductivity, body fat, and muscle mass, as well as hydration levels, can lead to significant variations in how pain is perceived and tolerated.[13]

The implications of this study are far-reaching. In rehabilitation, where EMS is used for muscle strengthening[14] and recovery,[15] understanding individual pain tolerance can guide the adjustment of EMS parameters for more effective and comfortable treatment. In pain management, comprehending how different body compositions and skin parameters affect pain perception can lead to more effective application of EMS, providing relief without causing undue discomfort.

In conclusion, this pilot study aims to shed light on the complex interaction between skin parameters, body composition, and pain tolerance to EMS stimuli in women. It endeavors to contribute to the development of more personalized and effective EMS protocols, enhancing the experience for female users across various applications, from fitness to therapeutic interventions. This research represents a step towards a deeper understanding of gender-specific responses to medical technologies, furthering the advancement of personalized medicine and treatment strategies.

Materials and Methods

Participants

The pilot study comprised 16 Caucasian females aged 18 to 54 years, mean age 35.9 ± 12.3 years (Table 1). The BMI of the study participants ranged from 20.2 to 28.8 kg/m2, the mean was 22.3 ± 2.3 kg/m2 (Table 1). Exclusion criteria for the study included: being under the age of majority; the presence of moles and skin integrity disorders in the treatment

Table 1 Age and Anthropometric Parameters of the Studied Women

	Median	Q1	Q3	Min	Max	Mean	SD
Age [year]	39.0	23.5	45.0	18.0	54.0	35.9	12.3
Height [cm]	167.0	165.3	170.0	157.0	178.0	167.4	5.1
Weight [kg]	61.2	58.6	65.7	51.7	75.0	62.6	6.5
*Weight [%]	100.6	97.1	107.4	92.9	134.1	103.9	10.6
BMI [kg/m^2]	21.6	20.9	23.1	20.0	28.8	22.3	2.3
Waist [cm]	70.5	68.5	76.3	64.0	88.0	72.8	7.0
Torso circumference (naval level) [cm]	80.5	77.0	85.5	71.5	95.0	81.8	7.1
Hip circumference [cm]	89.0	85.3	90.8	79.5	102.0	89.2	6.2
Skinfold thickness [mm]	28.0	21.0	38.0	10.0	52.0	29.3	11.7
WHtR (Waist to Height Ratio)	0.48	0.46	0.51	0.43	0.59	0.49	0.04
WHR (Waist-Hip Ratio)	0.93	0.89	0.95	0.80	0.98	0.92	0.05

Notes: *a result was compared to the average value determined by the analyzer for a woman of certain height.
Abbreviations: Q1, first quartile; Q3, third quartile; Min, minimum; Max, maximum; Mean, average; SD, standard deviation.

area; having a pacemaker; the presence of metal implant in the body, and permanent implant in the treated area; a history of cancer or post-cancerous conditions; severe conditions, such as cardiac disorders, epilepsy, uncontrolled hypertension, and liver or kidney diseases; impaired immune system due to immunosuppressive diseases such as AIDS (acquired immune deficiency syndrome) and HIV (human immunodeficiency virus), or use of immunosuppressive medications; patients with history of diseases stimulated by heat, such as recurrent Herpes Simplex in the treatment area; poorly controlled endocrine disorders, such as diabetes or thyroid dysfunction; any active condition in the treatment area, such as sores, psoriasis, eczema, and rash; history of skin disorders, keloids, abnormal wound healing, as well as very dry and fragile skin; history of bleeding coagulopathies or use of anticoagulants in the last 10 days; any surgery in treated area within 6 months prior to treatment; intra-dermal or superficial sub-dermal areas that have been injected with HA (hyaluronic acid)/collagen/fat injections or other augmentation methods with bio-material during last 6 months; having received treatment with light, laser, RF (radio frequency), or other devices in the treated area within 3 months; use of Isotretinoin (Accutane®) within 6 months prior to treatment; use of non-steroidal anti-inflammatory drugs (NSAIDS, eg, ibuprofen-containing agents) one week before and after each treatment; pregnancy and nursing. The study was authorized by the Bioethics Committee of the Medical University of Silesia, Katowice (Reference: KNW/0022/KB1/27/I/16). All participating individuals provided written informed consent, having been duly apprised of the study's methodology, objectives, potential adverse effects, and the measures implemented for the secure processing of personal data. The research was conducted in the Department of Basic Biomedical Sciences, Faculty of Pharmaceutical Sciences, Sosnowiec, Medical University of Silesia in Katowice.

Procedure

Body Composition Analysis and Anthropometric Measurements

Before the EMS/RF procedure, the body composition analysis was performed along with the anthropometric measurements such as: (1) the widest torso circumference measured at the top of the hip bones (hip circumference), (2) the narrowest torso circumference (waist circumference), (3) the torso circumference measured at navel level, (4) the skinfold thickness with a caliper directly to the side of belly button about 5 cm. The following calculations were made using the collected measurements:

- Body Mass Index (BMI) was calculated using the formula BMI = body weight [kg] / (height [m])^2.
- Weight [%] was determined by comparing each woman's body weight to the average weight of women of similar height. A value of 100% indicates that a woman's weight is equivalent to the average weight of a women with a similar height. The average population values were sourced from the norms provided by the InBody S10 (BioSpace; Seoul, Republic of Korea) (Supplementary Figure 1), body composition analyzer used in the study.
- Waist to Height Ratio (WHtR) was calculated using the formula WHtR = waist circumference at the level of the navel [cm] / height [cm].
- Waist-Hip Ratio (WHR) was calculated using the formula WHR = waist circumference [cm] / hip circumference [cm].

Both direct anthropometric measurements and these calculated indices were used for further statistical analysis.

All participants underwent Bioelectrical Impedance Analysis (BIA) using an InBodyS10 device to assess body composition. The electricity parameters during the bioimpedance measurement were as follows: Impedance Z (Ω): 1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, and 1 MHz; Reactance X (Ω): 5 kHz, 50 kHz, and 250 kHz; Whole Body Phase Angle Ø (°): 50 kHz. Prior to the body composition assessment, the heights and weights of the subjects were recorded using a Momert 5967 electronic column scale with a height rod (Hungary), with an accuracy of d = 100 g and maximum capacity = 200 kg. Participants refrained from eating for a minimum of 4 hours preceding the test. Just before the measurements, they were instructed to empty their bladders and then remain in a supine position for 15 min. Following this, electrodes were attached to the thumbs and middle fingers of both hands, as well as the ankles of both legs, for the analysis (Supplementary Figure 2). The following body composition parameters were used for further analyses: Protein [kg], Minerals [kg], BCM (Body Cell Mass) [kg], Fat [kg], PBF (Percent Body Fat) [%], VFA (Visceral Fat Area) [cm^2], FFM (Fat Free Mass) [kg], SLM (Soft Lean Mass) [kg], SMM (Skeletal Muscle Mass) [kg], TBW (Total Body Water)

[l], ICW (Intracellular Water) [l], ECW (Extracellular Water) [l], ECW/TBW edema index, and the following trunk parameters obtained in segmental measurement: SLM [kg], TBW [l] and ECW/TBW edema index. Typically, the standards for various parameters assessed by a body composition analyzer differ for each individual, as they are adjusted based on the person's height and weight. In this scenario, the recorded value was benchmarked against the average standard value provided by the device. Parameters that were compared against these norms are denoted with an asterisk (*) and are presented as a percentage of the average normative value for the woman being examined.

High-Frequency Ultrasound

High-frequency ultrasound scans of the abdominal skin were captured 5 cm below the navel (lower abdomen region) using the DUB Skin Scanner 75 (TPM, Koln, Germany). The process employed a transducer with frequencies of 22 and 50 MHz, capable of imaging up to a depth of 15 mm and 4 mm respectively. The characteristics of the captured image included a resolution of 1024×384 pixels, a color depth of 256 bits, and a gain setting of 40 dB. These images were recorded as two-dimensional B-scans. Subsequent analysis focused on the thickness of the epidermal entrance echo and the echo density of the dermis. The subsequent analyses incorporated the following parameters: Skin Thickness [µm], Epidermis Thickness [µm], and Dermis Density [a.u.].

Measurements of Tolerance to EMS Stimulus

Stimulation with the EMS was performed using Evolvex (InMode, Israel), the device used for body contouring that combined non-invasive radiofrequency (RF) and EMS. 4 EMS applicator units were applied to the treatment area with a belt to assume good coupling between applicators and skin: two applicators placed just above and two just below the navel, aligned with the rectus abdominis muscle on both sides. A thin layer of ultrasound gel was applied to the treated area between the skin and the applicator (Figure 1). The impulse voltage in the EMS generating device is 5 degrees higher than the value of "EMS intensity", a parameter specific for the device, so the EMS intensity of 10 means a voltage of 15V and a value of 50 means 55V. EMS intensity was set according to patient tolerance. The other parameters of the applied current are: biphasic pulse, pulse duration 400us, pulse series time 2s, and pulse frequency 80Hz. The intensity of the EMS was gradually increased from a starting threshold of 5, escalating until the participant experienced pain that prevented further continuation. The pain threshold at which this occurred was recorded.

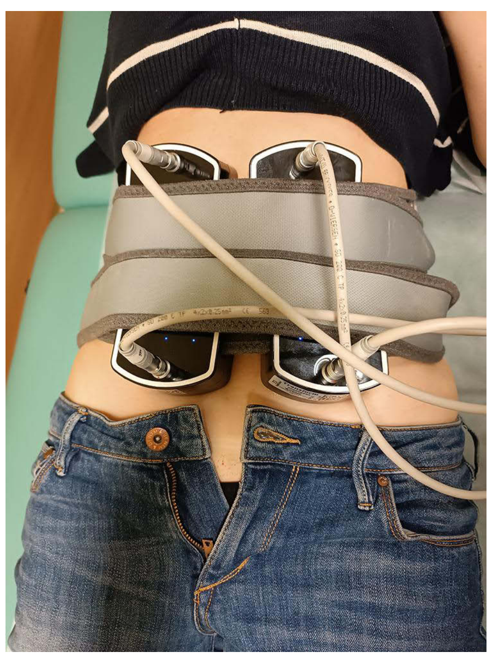

Figure 1 Location on the skin and method of applying the device generating the EMS stimulus.

Statistical Analysis

The database for statistical analysis and graphic presentations was prepared in a Microsoft Excel spreadsheet. It included the maximum intensity of the stimulus tolerated by the subjects, as well as data collected during interviews, anthropometric measurements, skinfold measurements, measurements made using a body composition analyzer, and ultrasound skin imaging. After additional calculations of indices and comparing some parameters to the average population values, the Excel spreadsheet was imported into the Statistica 13 software for statistical analysis. This analysis encompassed descriptive statistics, histogram analysis, and normality assessment in the Shapiro–Wilk test. Since not all variables exhibited a normal distribution, the correlation analysis was conducted using Spearman's rank correlation. Results were considered statistically significant at $p<0.05$.

Results

The maximum EMS intensity tolerated by the studied women ranged from 7 to 50, the median value was 28, and the lower and upper quartiles were 24 and 33, respectively (Figure 2). When described in the SI unit the maximum tolerated EMS stimulus varied from 12V to 55V, with a median of 33V.

The height of the examined women ranged from 157 to 178 cm, mean ± standard deviation 167 ± 5.1 cm (Table 1). Body weight ranged from 51.7 to 75.0 kg, mean ± standard deviation 62.6 ± 6.5 kg (Figure 3) (Table 1). The mean and standard deviation of the other anthropometric parameters and indicators were, respectively: body weight compared to the population mean 103.9 ± 10.6% (Figure 4), BMI 22.3 ± 2.3 kg/m2 (Figure 5), waist circumference 72.8 ± 7.0 cm, circumference at navel level 81.8 ± 7.1 cm, hip circumference 89.2 ± 6.2 cm (Figure 6), skinfold thickness 29.3 ± 11, 7 mm (Figure 7), WHtR 0.49 ± 0.04, WHR 0.92 ± 0.05.

Among the anthropometric parameters, total body weight $R=0.76$, $p<0.001$ and hip circumference $R=0.66$, $p<0.001$ had the strongest correlation with EMS intensity, and both had positive correlations (Table 2) (Figures 3 and 6). Positive, statistically significant correlations also occurred between EMS intensity and skinfold thickness ($R= 0.61$, $p=0.013$), between body weight compared to the average population value ($R=0.58$, $p=0.017$) and BMI value ($R= 0.56$, $p=0.023$) (Table 2) (Figures 4, 5 and 7).

Table 3 presents the descriptive statistics related to the analysis of body composition. The total mass of adipose tissue (fat mass) in the studied women ranged from 9.4 kg to 28 kg, with an average of 15.9 ± 5.26 kg (Figure 8). After

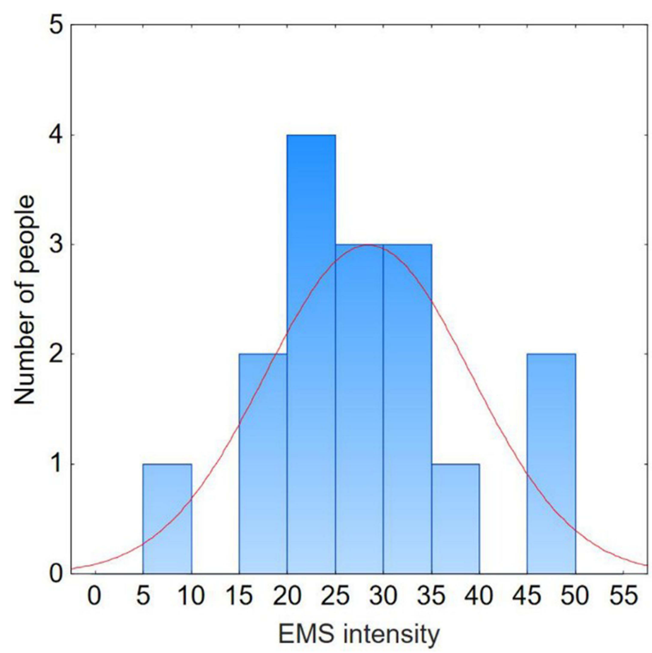

Figure 2 Histogram of EMS intensity.

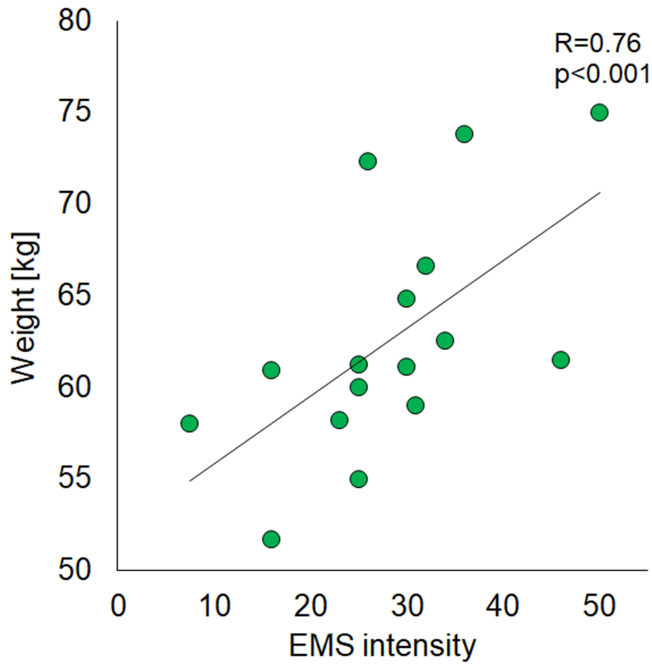

Figure 3 Correlations between the maximum EMS intensity and body weight.

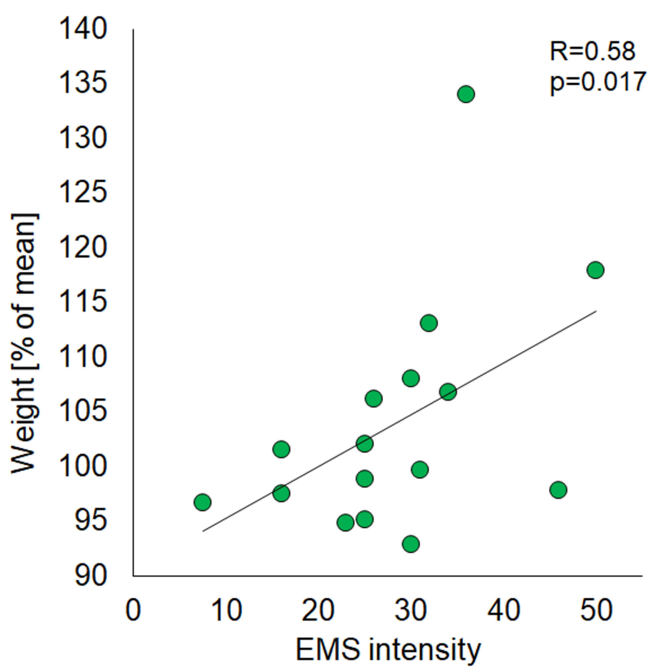

Figure 4 Correlations between the maximum EMS intensity and body weight compared to the population mean for certain height.

comparing the body fat mass of each of the participants to the average population values of the body fat mass, it was calculated that in the studied group the minimum body fat mass was 61.54% of the population mean, and the maximum was 195.80% of the population mean, on average 101.82 ± 35, 68% of the population mean (Figure 9). The PBF parameter calculated as the percentage of fat tissue in the total body weight ranged from 16.5 to 37.9%, the average was 25.02 ± 6.33% (Figure 10). Visceral fat area, calculated as the area of adipose tissue visible in a cross-section at the level of the navel, ranged from 34.50 to 135.70 cm^2, the average was 68.54 ± 27.23 cm2 (Figure 11). Based on the body water

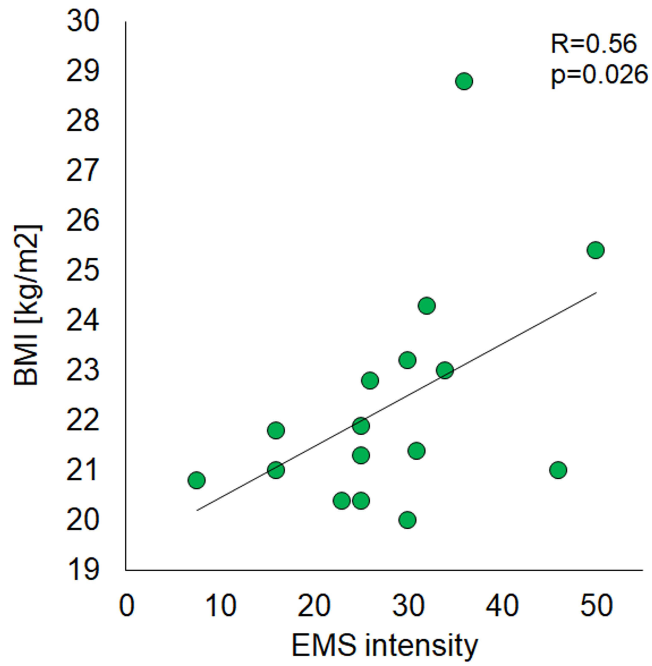

Figure 5 Correlations between the maximum EMS intensity and BMI.

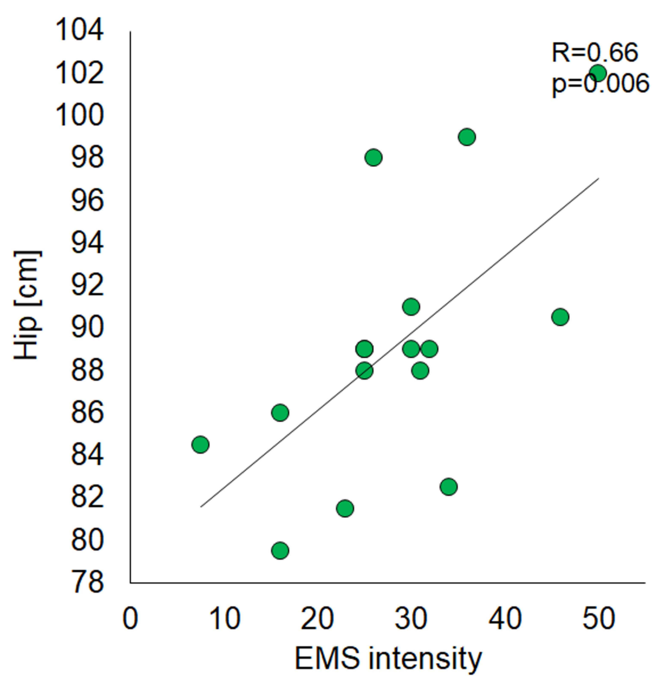

Figure 6 Correlations between the maximum EMS intensity and Hip circumference.

content parameters, the ratio of extracellular water to total body water (ECW/TBW) was calculated and a parameter called the edema index was obtained, it ranged from 0.367 to 0.385. In segmental analysis of the trunk, the edema index ranged from 0.369 to 0.386 (Figure 12).

The content of proteins, minerals and body cell mass in kilograms and converted into a percentage value compared to the population average, did not significantly correlate with the tolerance of the EMS stimulus (Table 4).

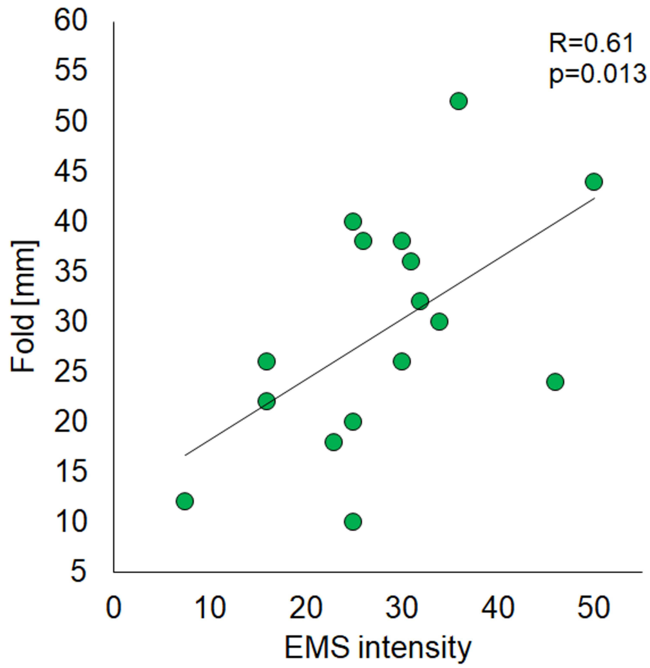

Figure 7 Correlations between the maximum EMS intensity and skinfold thickness.

In the study, a statistically significant relation was found between the body fat parameters of the examined women and their tolerance to EMS stimuli, as shown in Table 4 and Figures 8–11. The strongest positive correlation (R = 0.61, p = 0.012) was observed between the intensity of the EMS stimuli and the body fat mass [kg] (R=0,61, p=0,012) (Figure 8). Subsequently, a correlation was identified between the intensity of the EMS and the fat content compared to population averages (R = 0.58, p = 0.019), between EMS intensity and visceral fat area (R = 0.55, p = 0.029) (Figure 11) and between EMS intensity and PBF (R= 0.52, p=0.041).

There were no statistically significant correlations between the tolerance of the EMS stimulus and the content of fat free mass, soft lean mass, and skeletal muscle mass compared to average population values (Table 4).

Table 2 Correlation Between the Maximum EMS Intensity and Age with Anthropometric Parameters

	N	R	t(N-2)	p
Age [year]	16	−0.08	−0.29	0.777
Height [cm]	16	0.11	0.40	0.697
Weight [kg]	16	0.76	4.37	0.0006
*Weight [%]	16	0.58	2.70	0.017
BMI [kg/m^2]	16	0.56	2.56	0.023
Waist [cm]	16	0.36	1.42	0.177
Torso circumference (naval level) [cm]	16	0.38	1.52	0.150
Hip circumference [cm]	16	0.66	3.25	0.006
Skinfold thickness [mm]	16	0.61	2.86	0.013
WHtR (Waist to Height Ratio)	16	0.26	1.01	0.328
WHR (Waist-Hip Ratio)	16	−0.25	−0.97	0.348

Abbreviations: N, number of women; R, correlation coefficient; p, intensity level.

Table 3 Body Composition Analysis of the Studied Women

	Median	Q1	Q3	Min	Max	Mean	SD
Protein [kg]	9.20	8.70	9.85	7.70	10.60	9.20	0.81
*Protein [%]	99.01	96.46	108.24	88.76	110.42	100.70	6.84
Mineral [kg]	3.43	3.10	3.50	2.67	3.74	3.32	0.29
*Mineral [%]	105.53	100.65	110.69	94.12	116.23	105.00	6.60
Body Cell Mass [kg]	30.55	28.85	32.60	25.70	35.00	30.48	2.61
*Body Cell Mass [kg]	99.06	96.43	108.21	89.12	109.38	100.58	6.58
Fat [kg]	14.75	11.55	19.35	9.40	28.00	15.90	5.26
*Fat [%]	95.01	73.13	117.06	61.54	195.80	101.82	35.68
PBF (Percent Body Fat) [%]	24.80	19.35	28.85	16.50	37.90	25.02	6.33
VFA [cm2]	64.50	47.65	84.25	34.50	135.70	68.54	27.23
FFM (Fat Free Mass) [kg]	46.90	44.35	49.80	39.10	53.30	46.70	3.99
*FFM [%]	99.08	96.57	107.16	88.47	108.78	100.55	6.38
SLM (Soft Lean Mass) [kg]	44.00	41.70	46.85	36.90	50.20	43.92	3.76
*SLM [%]	98.70	96.17	106.71	88.13	108.66	100.21	6.37
SLM of trunk [kg]	20.35	19.30	22.15	17.60	23.70	20.51	1.85
*SLM of trunk [%]	101.52	96.59	108.35	91.67	116.39	102.47	7.47
SMM (Skeletal Muscle Mass) [kg]	25.80	24.30	27.70	21.40	29.80	25.74	2.39
*SMM [%]	99.26	96.01	108.95	87.90	109.96	100.62	7.18
TBW (Total Body Water) [l]	34.20	32.50	36.50	28.70	39.00	34.18	2.92
*TBW [%]	98.47	96.17	106.55	87.92	108.55	100.19	6.37
TBW of trunk [l]	15.90	15.00	17.20	13.70	18.40	15.95	1.44
*TBW of trunk [%]	13.16	13.14	13.19	13.10	13.23	13.16	0.03
ICW (Intracellular Water) [l]	21.35	20.15	22.80	18.00	24.40	21.29	1.82
*ICW [%]	99.33	96.51	108.15	89.27	109.42	100.71	6.57
ECW (Extracellular Water) [l]	12.85	12.35	13.80	10.70	14.60	12.88	1.12
*ECW [%]	97.78	95.42	105.43	85.71	107.75	99.28	6.29
ECW/TBW	0.378	0.374	0.382	0.367	0.385	0.377	0.005
ECW/TBW of trunk	0.379	0.374	0.382	0.369	0.386	0.378	0.005

Notes: *a result was compared to the average value determined by the analyzer for a woman of certain body parameters.

Abbreviations: Q1, first quartile; Q3, third quartile; Min, minimum; Max, maximum; Mean, average; SD, standard deviation.

There was also no correlation between the total body water content, extracellular and intracellular water content, the edema index (TBW/ECW) and the intensity of the EMS stimulus tolerated by women (Table 4). Among the body water parameters, the TBW/ECW edema index measured separately for the trunk had the strongest correlation with the

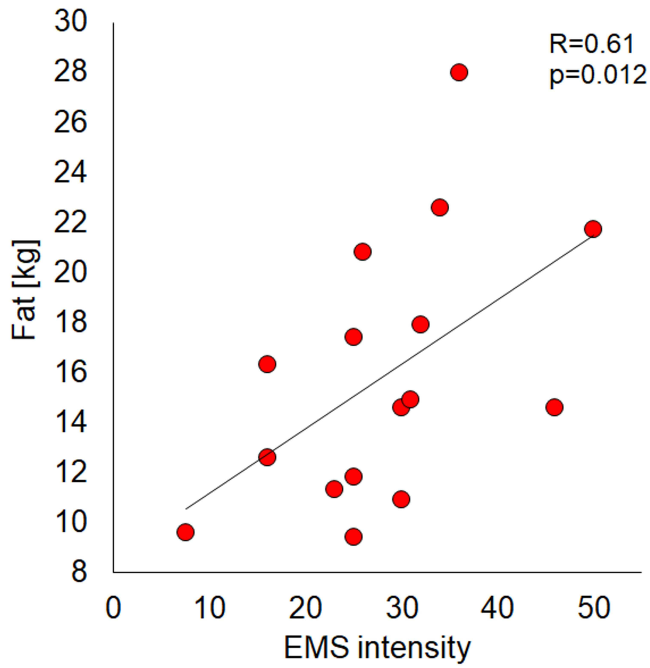

Figure 8 Correlation between the maximum intensity of the applied EMS stimulus and body fat mass.

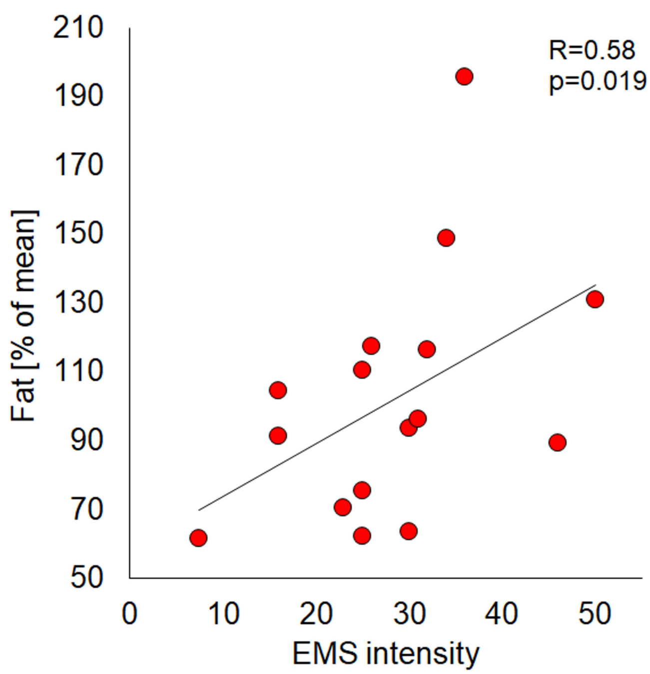

Figure 9 Correlation between the maximum intensity of the applied EMS stimulus and body fat mass expressed as a percentage of the average fat mass for women of a certain height.

tolerance of EMS stimulus (R= −0.42, p= 0.106), but the level of statistical significance was not reached (Table 4) (Figure 12).

The structure of the abdominal skin parameters of women participating in the study differed in thickness and density (Table 5). The thickness of the dermis ranged from 1426.0 to 1855.0 [µm], the thickness of the epidermis ranged from 78.0 to 197.0 [µm], and the density of the dermis ranged from 10.56 to 66.90 arbitrary units [a.u.]. Among the skin

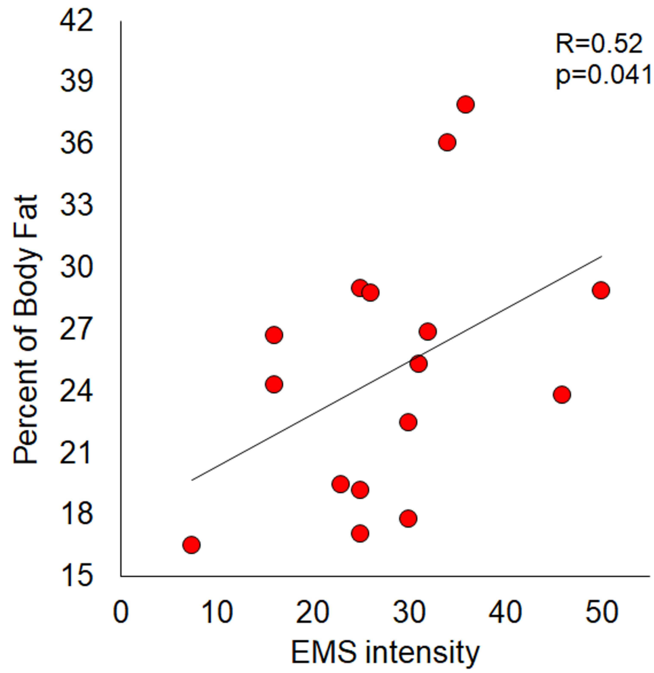

Figure 10 Correlation between the maximum intensity of the applied EMS stimulus and percentage of body fat in relation to the weight.

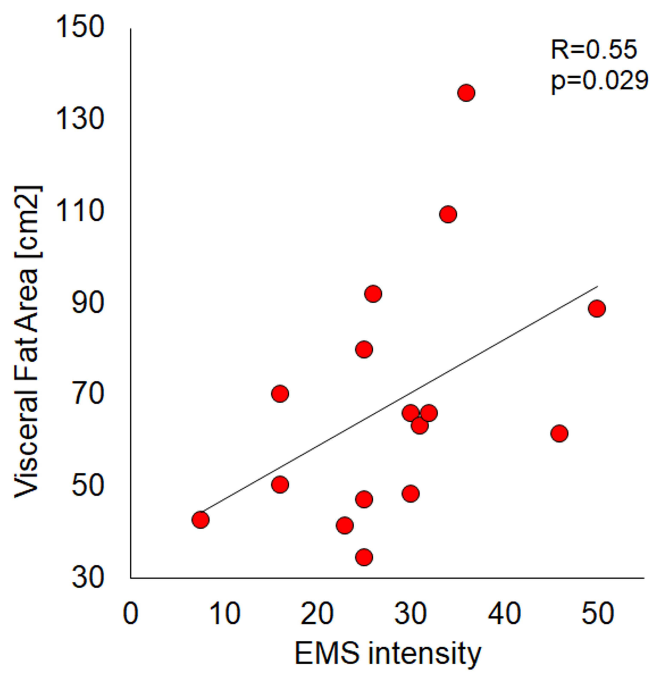

Figure 11 Correlation between the maximum intensity of the applied EMS stimulus and visceral fat area.

parameters, skin density correlated the most with the tolerance of EMS stimulus intensity (R=0.44, p=0.092), but it did not reach the level of statistical significance (Table 6) (Figure 13).

Discussion

The results analysis revealed differences in how women tolerate various intensities of EMS stimulus, which might be partially explained by anthropometric and body composition parameters. The hip circumference, measured at the top of the

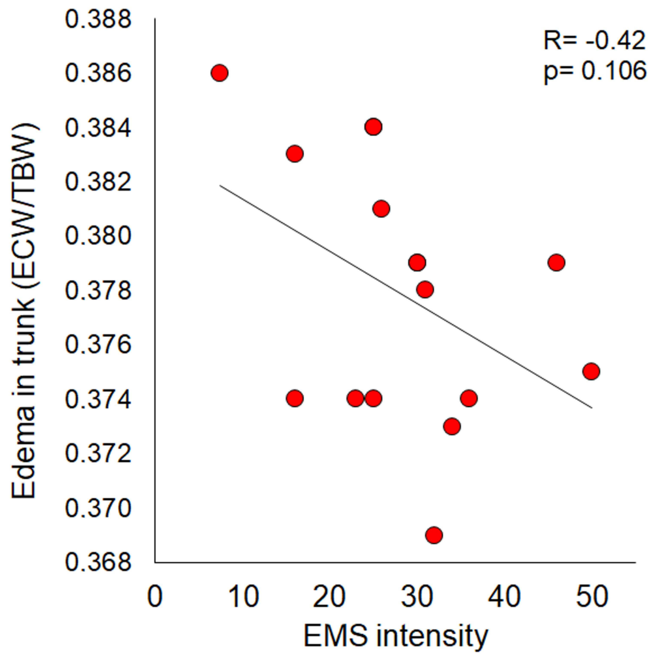

Figure 12 Correlation between the maximum intensity of the applied EMS stimulus and trunk edema index.

hip bones, showed the strongest correlation with EMS stimulus intensity. Additionally, significant correlations were found between the intensity of the EMS stimulus and parameters such as body weight relative to the population average, skinfold thickness, and BMI. The higher values in these parameters correlated with a higher tolerance for intense EMS stimuli.

Table 4 Correlation Between the Maximum Intensity of the EMS Stimulus and Body Composition Parameters

	N	R	t (N-2)	p
Protein [kg]	16	0.28	1.07	0.301
*Protein [%]	16	0.32	1.26	0.228
Mineral [kg]	16	0.26	1.01	0.330
*Mineral [%]	16	0.18	0.69	0.504
Body Cell Mass [kg]	16	0.25	0.95	0.357
*Body Cell Mass [%]	16	0.22	0.83	0.419
Fat [kg]	16	0.61	2.88	0.012
*Fat [%]	16	0.58	2.66	0.019
PBF (Percent Body Fat) [%]	16	0.52	2.25	0.041
VFA [cm^2]	16	0.55	2.43	0.029
FFM (Fat Free Mass) [kg]	16	0.26	1.02	0.324
*FFM [%]	16	0.27	1.07	0.303
SLM (Soft Lean Mass) [kg]	16	0.26	1.02	0.325
*SLM [%]	16	0.23	0.88	0.394

(*Continued*)

Table 4 (Continued).

	N	R	t (N-2)	p
SLM of trunk [kg]	16	0.37	1.50	0.156
*SLM of trunk [%]	16	0.22	0.86	0.406
SMM (Skeletal Muscle Mass) [kg]	16	0.25	0.95	0.357
*SMM [%]	16	0.22	0.84	0.416
TBW (Total Body Water) [l]	16	0.23	0.89	0.390
*TBW [%]	16	0.18	0.69	0.504
TBW of trunk [l]	16	0.37	1.50	0.156
*TBW of trunk [%]	16	−0.16	−0.61	0.552
ICW (Intracellular Water) [l]	16	0.25	0.95	0.357
*ICW [%]	16	0.20	0.77	0.456
ECW (Extracellular Water) [l]	16	0.19	0.73	0.477
*ECW [%]	16	0.11	0.42	0.679
ECW/TBW	16	−0.39	−1.58	0.135
ECW/TBW of trunk	16	−0.42	−1.73	0.106

Notes: *a result was compared to the average value determined by the analyzer for a woman of certain body parameters.
Abbreviations: N, number of women; R, correlation coefficient; p, intensity level.

Table 5 Skin Parameters Measured by High-Frequency Ultrasound

	Median	Q1	Q3	Min	Max	Mean	SD
Thickness of the dermis [μm]	1647.0	1587.0	1729.0	1426.0	1855.0	1654.6	105.6
Thickness of the epidermis [μm]	101.5	86.0	115.0	78.0	197.0	106.5	29.6
Density of the dermis [a.u.]	24.79	15.01	30.27	10.56	66.90	25.72	13.98

Abbreviations: Q1, first quartile; Q3, third quartile; Min, minimum; Max, maximum; Mean, average; SD, standard deviation.

Table 6 Correlation Between the Maximum Intensity of the EMS Stimulus and Skin Parameters Obtained in Ultrasound Measurement

	N	R	t (N-2)	p
Thickness of the dermis [μm]	16	−0.19	−0.74	0.474
Thickness of the epidermis [μm]	16	−0.04	−0.14	0.889
Density of the dermis [a.u.]	16	0.44	1.81	0.092

Abbreviations: N, number of women; R, correlation coefficient; p, level of EMS intensity.

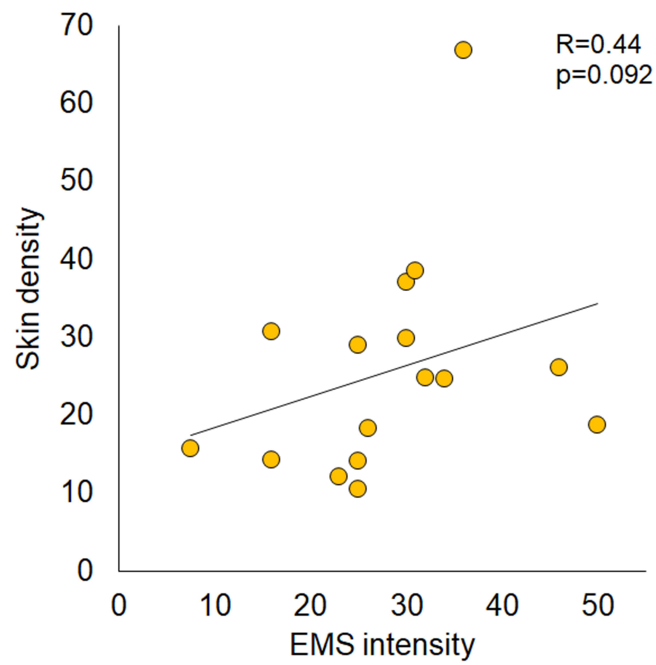

Figure 13 Correlation between the maximum intensity of the applied EMS stimulus and skin density.

Within the body composition analysis parameters, statistically significant correlations were evident between the EMS stimulus intensity and factors related to fat tissue content. These factors included body fat mass, body fat mass relative to population average values, visceral fat area, and the percentage of body fat.

Several hypotheses have been proposed to explain the observed relationships. A key factor may be the ratio of the electrode surface area to the abdominal surface and the overall volume of the torso. While direct measurements do not yield the abdominal area, they do provide total body weight and hip circumference, both of which have shown strong correlations with the tolerance of EMS intensity. It's hypothesized that in individuals with smaller body frames and narrower hip circumferences, a proportionally greater amount of energy reaches the muscles, leading to more intense stimulation. This increased stimulation might result in discomfort or even pain. Beneath the skin, where the electrodes are placed, lie the rectus abdominis muscles. In individuals with a smaller body circumference, the electrodes cover a relatively larger muscle area compared to those with a larger body circumference. Consequently, the contraction of a more extensive muscle group in smaller individuals is likely to cause more pain than the contraction of a smaller area in larger individuals.

Key factors associated with increased tolerance to EMS involve adipose tissue characteristics, notably the skinfold thickness. Patients' perceptions of the EMS varied, with the predominant sensations being tingling, pinching, and stinging, followed by muscle spasms and jerks. Notably, almost every individual could identify the exact moment of muscle activation during stimulation. In subjects with thicker skinfolds and higher adiposity, indicated by other parameters, the onset of painful muscle cramps was delayed. The work of Seno et al[16] further demonstrates that the body fat percentage plays a role in modulating sensitivity to electrical stimulation. A study conducted by Petrofsky J[17] examined the influence of subcutaneous fat on the transmission properties of electrical stimuli when applied to the skin for skeletal muscle activation. Findings indicated that individuals with higher subcutaneous fat levels required elevated current intensities to achieve muscle contraction. This is attributed to the fact that an increased fat layer results in higher resistance and lower capacitance, thereby causing more significant signal attenuation during transmission to the muscles. Consequently, the quantity of subcutaneous adipose tissue significantly affects the efficacy of electrical stimulation, impacting both the amplitude of the signal that reaches the muscles and the level of discomfort experienced by the patient.[17]

Contrarily, there was no statistically significant correlation between the tolerance to EMS intensity and body composition parameters pertaining to muscle tissue. The strongest observed correlation was between EMS intensity and Soft Lean Mass in the trunk, registering an R-value of 0.37 with a p-value of 0.156. Nevertheless, in the research conducted by Witkoś et al [18] it was demonstrated that the amount of muscle tissue plays a role in how electrical stimuli are perceived. Findings indicated that the electrical conductivity in fat tissue is less than that in muscle or blood, influencing how electric current propagates through the body. As a result, a higher proportion of muscle tissue decreases electrical resistance, thereby lowering the threshold for sensory perception. However, a different current was used, the one based on the principles of TENS (Transcutaneous Electrical Nerve Stimulation) with parameters of 100 Hz and 100 μs, and a biphasic waveform, was utilized as the sensory stimulus.[18]

Although water is a highly effective conductor of electricity,[19] this study did not establish a statistically significant relationship between body composition parameters related to total, intracellular, and extracellular water content and the tolerance to EMS stimulus intensity. Nevertheless, there was a minor trend indicating decreased EMS stimulus tolerance in individuals with higher edema index values in the trunk (ECW/TBW in trunk $R = -0.42$, $p=0.106$). It is important to note that all water-related parameters, including edema indicators, were within normal ranges in all the examined female subjects. This suggests that with a larger sample size and inclusion of subjects with abnormal water balance, the correlation between electrical conductivity and body water content might be more pronounced.

The results of this experiment are in contrast to the results of other authors. Seno et al[16] compared the current perception threshold (CPT) for electrical stimulation among individuals with different body water percentages, indicating that body water content is an important factor influencing the perception threshold for electrical stimulation. Similarly, the study of Witkoś et al[18] demonstrated that individuals with higher body water content have a lower threshold for the perception of electrical current. Electrical current flows through the body, preferring tissues with higher water content as they offer less resistance.

Additionally, the water content in the skin, along with its thickness and density, were identified as contributing factors that could affect the range of tolerance for the EMS stimulus. However, this pilot study indicated that variations in the abdominal skin structure of women, such as thickness and density, might influence their tolerance to EMS stimuli. However, this relationship was not found to be statistically significant in the group analyzed. Based on the information provided by Kruglikov,[20] it can be concluded that the thickness of the skin (dermis thickness) plays a crucial role in electrical stimulation. The author analyzed current in the context of radiofrequency (RF) treatment. The layered structure of the skin, including the dermis and subcutaneous white adipose tissue, significantly alters the distribution of the RF current.[20] Consequently, the researchers of this study have postulated the hypothesis that variables such as the thickness of the epidermis and dermis, as well as their density, might play a significant role in determining an individual's tolerance to EMS stimuli. This hypothesis, however, proved to be incorrect, or alternatively, a larger sample size might be required to adequately elucidate these relationships.

The primary limitation of this study stems from its pilot status, characterized by a limited number of participants, which constrains the generalizability of the findings.[21] However, the results elucidated below identify critical variables that influence the reception of electrical stimuli. These variables warrant closer examination in future studies with expanded participant groups. Furthermore, it is advisable to conduct subsequent research with populations not represented in these preliminary studies, including male subjects and individuals of diverse ages and body compositions, to enhance the breadth and applicability of the findings.

Conclusion

The study's findings provide several key insights into women's tolerance to Electrical Muscle Stimulation, revealing important correlations and factors that can guide personalized EMS therapy for enhanced effectiveness and comfort. Firstly, tolerance to the EMS stimulus is strongly correlated with an increase in the following anthropometric parameters: hip circumference, body weight, skinfold, and BMI. In terms of body composition, there is a significant link between EMS intensity and adipose tissue factors, such as body fat mass and percentage. Interestingly, no correlation was found between EMS tolerance and muscle tissue parameters or water content, though a minor trend suggests a lower tolerance in individuals with higher trunk edema index values. Additionally, variations in abdominal skin structure, including thickness and density, do not influence EMS tolerance. These insights are vital as elevated levels of discomfort often lead to the termination of treatment sequences, which hinders the achievement of aesthetic objectives. Thus, the findings hold potential significance for various electrostimulation-based treatments in both aesthetic and rehabilitative contexts.

Abbreviations

EMS, electrical muscle stimulation; BIA, bioelectrical impedance analysis; BMI, body mass index; AIDS, acquired immune deficiency syndrome; HIV, human immunodeficiency virus; HA, hyaluronic acid; RF, radio frequency; NSAIDS, non-steroidal anti-inflammatory drugs; WHtR, waist to height ratio; WHR, waist-hip ratio; BCM, body cell mass; PBF, percent body fat; VFA, visceral fat area; FFM, fat free mass; SLM, soft lean mass; SMM, skeletal muscle mass; TBW, total body water; ICW, intracellular water; ECW, extracellular water; Q1, first quartile; Q3, third quartile; SD, standard deviation; TENS, transcutaneous electrical nerve stimulation; CPT, current perception threshold.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Bioethics Committee of the Medical University of Silesia (Reference: KNW/0022/KB1/27/I/16). Written informed consent was obtained from all participants.

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Disclosure

The authors report no conflicts of interest in this work.

References

1. Ahmad MF, Hasbullah AH. The effects of electrical muscle stimulation (EMS) towards male skeletal muscle mass. *Int J Sport Health Sci*. 2015;9 (12):864–873.
2. Knibbe J, Alsmith A, Hornbæk K. Experiencing electrical muscle stimulation. *Proc ACM Intera We Ubi Tech*. 2018;2(3):1–14. doi:10.1145/3264928
3. Nakamura K, Nakano H, Naraba H, Mochizuki M, Hashimoto H. Early rehabilitation with dedicated use of belt-type electrical muscle stimulation for severe COVID-19 patients. *Critical Care*. 2020;24(1):1–2. doi:10.1186/s13054-020-03080-5
4. Fu T, Jiang L, Peng Y, et al. Electrical muscle stimulation accelerates functional recovery after nerve injury. *Neuroscience*. 2020;426:179–188. doi:10.1016/j.neuroscience.2019.10.052
5. Hwang UJ, Jung SH, Kim HA, Kim JH, Kwon OY. Effect of abdominal electrical muscle stimulation training with and without superimposed voluntary muscular contraction on lumbopelvic control. *J Sport Rehab 2020*. 2020;29(8):1137–1144. doi:10.1123/jsr.2019-0348
6. Berger J, Becker S, Backfisch M, Eifler C, Kemmler W, Fröhlich M. Adjustment effects of maximum intensity tolerance during whole-body electromyostimulation training. *Front Physiol*. 2019;10:920. doi:10.3389/fphys.2019.00920
7. Witkoś J, Fusińska-Korpik A, Hartman-Petrycka M, Nowak A. An assessment of sensory sensitivity in women suffering from depression using transcutaneous electrical nerve stimulation. *PeerJ*. 2022;10:e13373.
8. Berkley KJ, Hoffman GE, Murphy AZ, Holdcroft A. Pain: sex/gender differences. In: Pfaff DW, Arnold AP, Fahrbach SE, Etgen AM, Rubin RT, editors. *Hormones, Brain and Behavior*. Academic Press; 2002:409–442.
9. Hussain AM, Khan FA, Ahmed A, Chawla T, Azam SI. Effect of gender on pain perception and analgesic consumption in laparoscopic cholecystectomy: an observational study. *J Anaesthesiol Clin Pharmacol*. 2013;29(3):337. doi:10.4103/0970-9185.117095
10. Xu X, Zhang H, Yan Y, Wang J, Guo L. Effects of electrical stimulation on skin surface. *Acta Mech Sin*. 2021;1–29.
11. Berger J, Becker S, Ludwig O, Kemmler W, Fröhlich M. Whole-body electromyostimulation in physical therapy: do gender, skinfold thickness or body composition influence maximum intensity tolerance? *J PhyTherapy Sci*. 2020;32(6):395–400. doi:10.1589/jpts.32.395
12. Wackerhage H, Schoenfeld BJ. Personalized, evidence-informed training plans and exercise prescriptions for performance, fitness and health. *Sports Medicine*. 2021;51(9):1805–1813. doi:10.1007/s40279-021-01495-w
13. Mogil JS. Qualitative sex differences in pain processing: emerging evidence of a biased literature. *Nat Rev Neurosci*. 2020;21(7):353–365. doi:10.1038/s41583-020-0310-6
14. Mukherjee S, Fok JR, van Mechelen W. Electrical stimulation and muscle strength gains in healthy adults: a systematic review. *J Strength Cond Res*. 2022;1:10–1519.
15. Pinar S, Kaya F, Bicer B, Erzeybek MS, Cotuk HB. Different recovery methods and muscle performance after exhausting exercise: comparison of the effects of electrical muscle stimulation and massage. *Biol Sport*. 2012;29(4):269–275. doi:10.5604/20831862.1019664
16. Seno SI, Shimazu H, Kogure E, Watanabe A, Kobayashi H. Factors affecting and adjustments for sex differences in current perception threshold with transcutaneous electrical stimulation in healthy subjects. *Neuromodulation*. 2019;22(5):573–579. doi:10.1111/ner.12889

17. Petrofsky J. The effect of the subcutaneous fat on the transfer of current through skin and into muscle. *Med Eng Phys*. 2008;30(9):1168–1176. doi:10.1016/j.medengphy.2008.02.009
18. Witkoś J, Hartman-Petrycka M, Błażejewski G. The effects of sex, women's body composition and monthly cycle phases on the sensory threshold of upper limb to transcutaneous electrical nerve stimulation in healthy subjects. *Appl Sci*. 2023;13(14):8365. doi:10.3390/app13148365
19. Ward LC. Bioelectrical impedance analysis for body composition assessment: reflections on accuracy, clinical utility, and standardisation. *Eur J Clin Nutr*. 2019;73(2):194–199. doi:10.1038/s41430-018-0335-3
20. Kruglikov IL. Influence of the dermis thickness on the results of the skin treatment with monopolar and bipolar radiofrequency currents. *Biomed Res Int*. 2016;2016:1–6. doi:10.1155/2016/1953203
21. Elman C, Gerring J, Mahoney J. *The Production of Knowledge: Enhancing Progress in Social Science*. Cambridge University Press; 2020.