



Original Article

Whole-body electromyostimulation in physical therapy: do gender, skinfold thickness or body composition influence maximum intensity tolerance?

JOSHUA BERGER^{1)*}, STEPHAN BECKER¹⁾, OLIVER LUDWIG¹⁾, WOLFGANG KEMMLER²⁾,
MICHAEL FRÖHLICH¹⁾

¹⁾ Department of Sports Science, Technische Universität Kaiserslautern: 67663 Kaiserslautern, Germany

²⁾ Institute of Medical Physics, Friedrich-Alexander University of Erlangen, Germany

Abstract. [Purpose] Whole-body electromyostimulation (WB-EMS) is an extension of the EMS application known in physical therapy. In WB-EMS, body composition and skinfold thickness seem to play a decisive role in influencing the Ohmic resistance and therefore the maximum intensity tolerance. That is why the therapeutic success of (WB-)EMS may depend on individual anatomical parameters. The aim of the study was to find out whether gender, skinfold thickness and parameters of body composition have an influence on the maximum intensity tolerance in WB-EMS. [Participants and Methods] Fifty-two participants were included in the study. Body composition (body impedance, body fat, fat mass, fat-free mass) and skinfold thicknesses were measured and set into relation to the maximum intensity tolerance. [Results] No relationship between the different anthropometric parameters and the maximum intensity tolerance was detected for both genders. Considering the individual muscle groups, no similarities were found in the results. [Conclusion] Body composition or skinfold thickness do not seem to have any influence on the maximum intensity tolerance in WB-EMS training. For the application in physiotherapy this means that a dosage of the electrical voltage within the scope of a (WB-) EMS application is only possible via the subjective feedback (BORG Scale).

Key words: Skinfold thickness, Body fat, Maximum intensity tolerance

(This article was submitted Jan. 29, 2020, and was accepted Mar. 24, 2020)

INTRODUCTION

Electromyostimulation (EMS) is a method that has long been known in physiotherapy to strengthen the muscles¹⁾. Muscular atrophy, for example after prolonged bed rest or in the context of systemic diseases, can be demonstrably treated by the accompanying use of EMS. EMS is based on the application of an electrical field via electrodes attached to the skin, which stimulates the contraction of muscle fibres by altering muscle membrane potentials²⁾. Depending on the stimulation frequency used, the efferent nerves are obviously not directly excited³⁾. In recent years, Whole-body Electromyostimulation (WB-EMS) has found its way into therapeutic training. Here, large muscle areas are simultaneously activated via electrodes incorporated in the vests⁴⁾.

The principle of WB-EMS requires an arbitrary movement during the application of the current so that central nervous paths are activated^{5, 6)}. This additional involuntary contraction can lead to a higher training stimulus than the voluntary contraction in conventional strength training alone. Previous studies show significant increases in strength through EMS

*Corresponding author. Joshua Berger (E-mail: joshua.berger@sowi.uni-kl.de)

©2020 The Society of Physical Therapy Science. Published by IPEC Inc.



This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License. (CC-BY-NC-ND 4.0: <https://creativecommons.org/licenses/by-nc-nd/4.0/>)

application in both healthy people and patients^{2, 7, 8}).

The use of WB-EMS in physiotherapeutic practice shows that it is difficult to determine the strength of the applied electric tension in advance. In most cases, the strength of the electrostimulation is assessed by the patient on a BORG scale, thus determining the individually tolerable voltage. It can be assumed that the maximum intensity tolerance could be influenced by anthropometric parameters and individual's body composition. The applied current in WB-EMS must pass different skin layers, fat, and connective tissue as well as other physical structures (blood vessels, bones, ligaments) before it reaches the muscle to be stimulated. These individual structures are regarded as resistors (R) connected in series, that results in splitting up the applied voltage (U). According to Ohm's law, the current intensity (I) that flows through the muscle should therefore be dependent on the thickness of the skinfold above it⁹). Previous studies tried to verify these assumptions. However, the connection between maximum intensity tolerance and skinfold thickness could not be clarified unambiguously due to diverging results^{10, 11}). In this context, some patients' inability to tolerate certain EMS electric current applications is the main reason for the failure of these therapies¹²). Therefore, for the application in physiotherapy it would be helpful to know if there is a correlation between skinfold thickness, gender, body composition and the applied tension, since the latter influences the number of activated muscle fibers, but at the same time, via activation of the subcutaneous pain receptors, the maximum tolerable voltage limits the application. Therefore, the hypothesis of this study was that body composition (body impedance, body fat, fat mass, fat-free mass (FFM)) and a higher skinfold thickness have an influence on the maximum current intensity tolerance in WB-EMS training.

PARTICIPANTS AND METHODS

A total of 59 healthy WB-EMS novices were included in the longitudinal, observational panel design analysis. All participants conducted four consecutive tests to analyze their maximum current intensity. Due to health complications (three flu-like infections; two injuries not related to WB-EMS) and personal reasons (n=2), seven participants had to be excluded from the analysis, which allowed data evaluation with 52 volunteers (38 males: 23.4 ± 2.4 years, 181.8 ± 6.6 cm, 80.4 ± 8.8 kg; 14 females: 24.9 ± 3.9 years, 167.8 ± 5.1 cm, 65.8 ± 7.9 kg). All participants were EMS novices, included in the study after reviewing the exclusion criteria with a detailed anamnesis questionnaire. The exclusion criteria included the current guidelines for relative and absolute contraindications, which exclude all possible risk factors against WB-EMS training¹³). The participants were between 18–40 years old with a BMI <30 kg/m², internally and orthopedically healthy and not taking any medication that could have influenced the outcome of the study (e.g., analgesics). All volunteers received detailed information about the study design and all risks before the start of the study. Furthermore, they provided written informed consent to the procedure and the use of the data. The study was performed according to the current Declaration of the Helsinki guidelines¹⁴) and approved by the ethics commission of the German University for Prevention and Health Care Management (02/17).

To determine the maximum intensity tolerance of each participant, the miha bodytec 2 WB-EMS device from miha bodytec (Gersthofen, Germany) was used. The device consists of one main controller and 10 subcontrollers, each one for a specific muscle group. Eight of the subcontrollers are assigned to predefined muscle groups, two of the controllers (canal nine and ten) can be used to stimulate further muscle groups with additional electrodes. In this study, we focused on the eight predefined muscle groups (1. thighs, 2. gluteus, 3. lower back, 4. latissimus, 5. upper back, 6. abdomen, 7. chest, and 8. upper arms). During the examination, the electrodes were placed on a special EMS lingerie to avoid direct skin contact and potentially resulting irritations. The electrodes on the lower back, upper back, latissimus, abdomen, and chest are sewed into an electrode vest; thighs, gluteus, and upper arms are stimulated over additional electrode slings.

Body composition parameters (body impedance, body fat, fat mass, fat-free mass (FFM)) were determined using the Tanita BC-418 body composition monitor with the GMON v.3.2.3 software (Tanita Europe BV, Amsterdam, Netherlands). To ensure consistency and reliability skinfold thicknesses of the stimulated muscle groups were always measured by the same experienced test leader by means of the Harpenden Skinfold caliper (Harpenden, Burges Hill, UK). All skinfold values of the regions to be stimulated were recorded in millimeters (mm). [Figure 1](#) shows the positioning of the electrodes and the corresponding measuring point of the skinfold thickness (line on the electrode)¹⁵). In order to provide a statement about the development of the whole body, the values were summarized in an unweighted, additive index. Therefore, it was possible to observe potential correlations of the maximum intensity tolerance with the respective muscle groups as well as with the whole body.

To identify an individual maximum intensity tolerance, four consecutive tests were conducted. The tests were performed at the same time of the day by each participant to exclude time-of-day effects, with a one-week break between the tests to guarantee complete regeneration. Furthermore, the participants were examined by the same test leader at each successive test in order to ensure consistency and reliability. All muscle groups were individually stimulated until they reached their subjective maximum, i.e., that point at which the participant gave the stopping signal because the current flow reached the degree of maximum tolerance, associated with an uncomfortable feeling of tingling, itching, or pain. The volunteers were not informed about their individual values at any time of the study so that the level of the maximum intensity tolerance would not be influenced by motivational aspects. During the treatment, the common parameters of a WB-EMS application were used (stimulation frequency of 85 Hz, impulse width of 350 μ s, bipolar rectangular impulse, interchanging 4-s load and 4-s

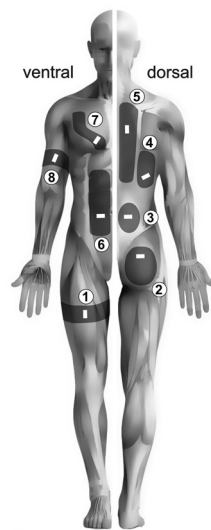


Fig. 1. Positioning of the electrodes (grey shaded areas) and position and alignment of the measuring points of the skinfolds (lines).

break)¹⁶). The Miha bodytec device does not provide any information about the voltage applied, so device-specific units (0–99) were used for further analysis. The device guaranteed a maximum output for each muscle group with the main level controller set to 99, so that a fine adjustment (values between 0–99) was performed for each muscle group. The individual muscle groups were regarded separately and then combined into an unweighted, additive index to observe the development of the whole body. As with the investigation of Berger et al., the intensity values of the third test were used for further analysis¹⁷.

The statistical analysis was performed using IBM SPSS (SPSS Version 25.0, Chicago, IL, USA). The analysis included two steps: As a first step, the global parameters (summed skinfold thickness, body impedance, body fat, fat mass, FFM) were compared with the maximum intensity values by means of multiple linear regression. For this purpose, two unweighted additive index values were calculated for each participant, adding up all skinfold values and all maximum intensity values for all muscle groups. In the second step, linear regression was applied to analyze all eight stimulated muscle groups individually to find out whether a relationship might exist between the local skinfold thicknesses and the local maximum intensity values using. All preconditions for the statistic tests were checked and confirmed in advance¹⁸). The evaluation was gender-specific in each case in order to identify potential differences.

RESULTS

The descriptive evaluation of the parameters for the whole body is shown in [Table 1](#). A relationship to the maximum current intensity was not detected, neither for male ($p=0.23$; $R^2=0.06$), nor for female ($p=0.97$; $R^2=-0.707$).

[Table 2](#) shows the interrelationships between skinfold thickness and the maximum intensity values for all muscles groups for males and females. A correlation between skinfold thickness and current tolerance was found for the lower back ($p=0.02$, $R^2=0.173$) in males and for the gluteus ($p=0.023$, $R^2=0.538$) in females.

Table 1. Descriptive values in mean value \pm standard deviation

	n	Index maximum intensity tolerance (stage)	Index skinfold thickness (mm)	Body impedance (Ω)	Body fat (%)	Fat mass (kg)	Fat free mass (kg)
Males	38	71.3 \pm 9.4	12.7 \pm 3.7	548.0 \pm 43.4	14.1 \pm 4.5	11.5 \pm 4.5	69.0 \pm 6.8
Females	14	63.0 \pm 12.8	17.4 \pm 3.6	664.8 \pm 63.7	28.3 \pm 4.5	18.8 \pm 4.6	47.0 \pm 4.7

Table 2. Descriptive values for all muscles including linear regression

	Skinfold (mm)	Maximum intensity tolerance (stage)	p	Linear regression	
				F	R ²
Males (n=38)					
Thighs	12.6 ± 5.7	78.3 ± 12.6	0.791	0.073	-0.066
Gluteus	18.4 ± 4.0	80.3 ± 13.9	0.053	4.516	0.201
Lower back	13.4 ± 4.4	69.3 ± 18.2	0.020*	6.215	0.173
Upper back	11.2 ± 3.3	61.8 ± 15.9	0.451	0.586	-0.016
Latissimus	11.6 ± 4.1	75.8 ± 14.9	0.090	3.176	0.094
Abdomen	18.6 ± 6.6	66.6 ± 15.0	0.806	0.063	-0.093
Chest	11.9 ± 4.9	84.1 ± 9.4	0.168	2.080	0.060
Upper arms	4.7 ± 1.3	60.0 ± 14.0	0.148	2.213	0.039
Females (n=14)					
Thighs	23.5 ± 7.0	71.2 ± 17.2	0.486	0.529	-0.049
Gluteus	26.1 ± 6.0	63.3 ± 17.8	0.023*	9.156	0.538
Lower back	18.2 ± 4.5	63.7 ± 13.9	0.759	0.100	-0.099
Upper back	12.5 ± 3.4	51.4 ± 24.8	0.067	4.116	0.206
Latissimus	16.4 ± 6.6	66.1 ± 18.9	0.904	0.015	-0.098
Abdomen	22.1 ± 5.4	61.8 ± 24.7	0.845	0.044	-0.236
Chest	10.9 ± 3.9	72.5 ± 20.8	0.831	0.050	-0.157
Upper arms	9.1 ± 2.3	49.6 ± 12.7	0.544	0.391	-0.053

Mean ± SD. *Significant values.

DISCUSSION

Based on the assumption that different skin layers, muscles, and fat tissue act as resistors connected in series, it is reasonable to suggest that thicker skinfolds have an influence on the maximum intensity tolerance due to the thicker subcutaneous fat tissue. Furthermore, body fat, fat mass, FFM, and total resistance of the body could have an influence, too. Nevertheless, this study did not confirm these assumptions. There seems to be no relationship between these parameters. Furthermore, no similarities were found between the results of males and females.

Previous studies found diverging results regarding the maximum intensity tolerance in EMS. Hortobágyi et al. examined the influence of an athlete's training condition on the maximum intensity tolerance in 12 male volunteers. The maximum tolerated intensity was measured on the biceps brachii muscle, resulting in a significantly higher intensity in strength training compared to an unexperienced group. The volunteers also differed in their anthropometric composition: at similar body sizes, the untrained showed a higher average body fat percentage. According to Ohm's law, this would result in an increased intensity tolerance because the thicker fatty tissue represents a stronger Ohmic resistance and therefore the flowing current would be lower. Contrary to this assumption, experienced volunteers with a lower body fat percentage achieved a higher maximum intensity tolerance. It is to be noted that only male volunteers were tested, so applying the results to both genders is impossible in this case. Contrary to the results of Hortobágyi et al., Medeiros et al. found a correlation between skinfold thickness and the maximum intensity tolerance in the quadriceps femoris muscle. Twenty females were divided into two groups based on their skinfold thickness at the dominant thigh. A maximum intensity current was applied. The result was a 24.2% higher intensity for the participants with thicker skinfolds compared to the ones with thinner skinfolds. Medeiros et al. concluded that the amount of subcutaneous fat tissue, based on the skinfold thickness, influences the maximum tolerated current intensity, but has no effect on the level of discomfort perception¹⁹). These results were confirmed by Miller et al.²⁰). In their study, 29 healthy females were examined concerning the interrelationship between skinfold thickness and the maximum tolerable voltage. They were able to determine an increasing maximum tolerable voltage with increasing skinfold thickness. However, Medeiros et al. as well as Miller et al. did not establish a subdivision with regard to the training condition of the participants. Furthermore, only females were tested, which makes it difficult to generalize the results, as gender-specific differences may occur as can be seen from the results of the present study.

Alon and Smith examined possible gender-specific differences with regard to the maximum tolerance of an EMS application on the quadriceps femoris muscle. They were able to detect a significantly higher current tolerance in males than in females¹²), but could not confirm their theory that the fitness level influenced the level of the maximum tolerable current intensity.

Maffiuletti et al. examined possible gender-specific differences in the sensory threshold of the quadriceps femoris muscle¹¹). They defined the sensory threshold as the point at which the participant indicated the initial perception of the electrical stimulus. The authors found highly significant differences between males and females, with males showing lower sensitivity. This means that females react more sensitively to electrostimulation than males and feel the applied current earlier. Furthermore, they detected the lowest sensory thresholds in those individuals with the largest skinfold thickness. This appears to be contrary to the assumed interrelationship between the skinfold thickness and the level of tolerance of the applied current.

As is shown in the studies presented, the findings are very divergent with regard to the specific influences, correlations and gender differences in relation to the maximum current intensity. In our study we did not find any clear gender-specific differences or influences of body composition or anthropometric characteristics on the maximum intensity tolerance in WB-EMS training. Considering the individual muscle groups, there were no consistent results for any of the genders, either. We found significant relationships for the maximum current intensity and skinfold thickness for the gluteus in female and for the lower back in male. These results cannot be clarified unambiguously at this point, as these significances cannot be clearly attributed to the body composition, which makes an interpretation very difficult. A possible approach in future studies could be the subdivision into different somatotypes in order to create possible subgroups on the basis of body fat distribution (ectomorphic, mesomorphic or endomorphic)²¹) and to trace potential results back to this, even if the test persons in our study had to some extent a uniform characterization because we mainly involved younger students. The influence of the skinfold thickness is probably reduced by other aspects as training condition or their mental attitude towards strength training. Hortobágyi et al., for example, explained the group difference based on the availability of the motor units, since untrained people show incomplete activation of the motor units and lower tolerance to external stimuli¹⁰). Other reasons could be an increased pain threshold or the muscle size of the trained persons, because it is known that the electrical properties of muscle tissue (e.g. bioimpedance) are strongly correlated with muscle size²²).

An important aspect that could explain the lack of a clear relationship between maximum current tolerance and skinfold thickness is the anatomy and stimulus physiology of the skin. The perception of pain caused by electric voltage takes place through pain receptors (nociceptors), not only in the muscle tissue but also in the (epi)dermis²³). It is known that the itching and tingling sensation caused by the application of an electric current is mediated by these receptors^{24, 25}). In most cases, our participants indicated excessive tingling as a criterion for stopping the electrical stimulation. Since the deeper lying subcutaneous fatty tissue has no influence on the electric current through near-surface structures, it is understandable why the skinfold thickness does not necessarily influence the maximum current tolerance.

In our study, only EMS novices participated in order to exclude an effect of any previous EMS experience. The participants were also instructed not to exercise intensively 3 days before the examination. However, athletic activity was not controlled for the division of subgroups. Furthermore, in our study (as well as in all other studies presented), the ambient temperature was not controlled precisely. Blood circulation in dependence of the surrounding temperature can also influence the level of the maximum tolerated current. A warmer environment promotes better blood circulation in areas close to the skin and could therefore influence the maximum intensity tolerance due to better conductivity²⁶). The extent to which this factor might have an influence on this study's results cannot be clarified unambiguously as all investigations were carried out under laboratory conditions and the temperature was not subject to control. However, there were no noticeable deviations from the normal room temperature, which was always between 20–22 degrees.

In conclusion, there seems to be no relationship between body composition parameters, skinfold thickness, and maximum intensity tolerance, neither in males, nor in females. For the application in physiotherapy this means that a dosage of the electrical voltage within the scope of a (WB-)EMS application is only possible via the subjective feedback (BORG Scale) of the patient.

Funding

This research received no external funding.

Conflicts of interest

The authors declare no conflict of interest.

ACKNOWLEDGMENT

The authors thank all participants for their contribution to the study.

REFERENCES

- 1) Avila M, Brasileiro J, Salvini T: Electrical stimulation and isokinetic training: effects on strength and neuromuscular properties of healthy young adults. *Braz J Phys Ther*, 2008, 12: 435–440. [[CrossRef](#)]
- 2) Filipovic A, Kleinöder H, Dörmann U, et al.: Electromyostimulation—a systematic review of the effects of different electromyostimulation methods on se-

- lected strength parameters in trained and elite athletes. *J Strength Cond Res*, 2012, 26: 2600–2614. [[Medline](#)] [[CrossRef](#)]
- 3) Gondin J, Guette M, Ballay Y, et al.: Electromyostimulation training effects on neural drive and muscle architecture. *Med Sci Sports Exerc*, 2005, 37: 1291–1299. [[Medline](#)] [[CrossRef](#)]
 - 4) Kemmler W, Schliffka R, Mayhew JL, et al.: Effects of whole-body electromyostimulation on resting metabolic rate, body composition, and maximum strength in postmenopausal women: the Training and ElectroStimulation Trial. *J Strength Cond Res*, 2010, 24: 1880–1887. [[Medline](#)] [[CrossRef](#)]
 - 5) Herrero AJ, Martín J, Martín T, et al.: Short-term effect of strength training with and without superimposed electrical stimulation on muscle strength and anaerobic performance. A randomized controlled trial. Part I. *J Strength Cond Res*, 2010, 24: 1609–1615. [[Medline](#)] [[CrossRef](#)]
 - 6) Amaro-Gahete FJ, De-la-O A, Sanchez-Delgado G, et al.: Whole-body electromyostimulation improves performance-related parameters in runners. *Front Physiol*, 2018, 9: 1576. [[Medline](#)] [[CrossRef](#)]
 - 7) Kemmler W, von Stengel S: Alternative exercise technologies to fight against sarcopenia at old age: a series of studies and review. *J Aging Res*, 2012, 2012: 109013. [[Medline](#)] [[CrossRef](#)]
 - 8) Berger J, Ludwig O, Becker S, et al.: Effects of an impulse frequency dependent 10-week whole-body electromyostimulation training program on specific sport performance parameters. *J Sports Sci Med*, 2020, 19: 271–281.
 - 9) Vatter J, Authenrieth S, Müller S: EMS Consulting and training manual. Glucker Kolleg: Stuttgart, 2016.
 - 10) Hortobágyi T, Lambert NJ, Tracy C, et al.: Voluntary and electromyostimulation forces in trained and untrained men. *Med Sci Sports Exerc*, 1992, 24: 702–707. [[Medline](#)]
 - 11) Maffiuletti NA, Herrero AJ, Jubeau M, et al.: Differences in electrical stimulation thresholds between men and women. *Ann Neurol*, 2008, 63: 507–512. [[Medline](#)] [[CrossRef](#)]
 - 12) Alon G, V Smith G: Tolerance and conditioning to neuro-muscular electrical stimulation within and between sessions and gender. *J Sports Sci Med*, 2005, 4: 395–405. [[Medline](#)]
 - 13) Kemmler W, Fröhlich M, von Stengel S, et al.: Whole-body electromyostimulation? The need for common sense! Rationale and guideline for a safe and effective training. *Dtsch Z Sportmed*, 2016, 67: 218–221. [[CrossRef](#)]
 - 14) World Medical Association: World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*, 2013, 310: 2191–2194. [[Medline](#)] [[CrossRef](#)]
 - 15) Parizková J, Bůžková P: Relationship between skinfold thickness measured by Harpenden caliper and densitometric analysis of total body fat in men. *Hum Biol*, 1971, 43: 16–21. [[Medline](#)]
 - 16) Filipovic A, Kleinöder H, Dörmann U, et al.: Electromyostimulation—a systematic review of the influence of training regimens and stimulation parameters on effectiveness in electromyostimulation training of selected strength parameters. *J Strength Cond Res*, 2011, 25: 3218–3238. [[Medline](#)] [[CrossRef](#)]
 - 17) Berger J, Becker S, Backfisch M, et al.: Adjustment effects of maximum intensity tolerance during whole-body electromyostimulation training. *Front Physiol*, 2019, 10: 920. [[Medline](#)] [[CrossRef](#)]
 - 18) Wolf C, Best H: Lineare Regressionsanalyse. In: *Handbuch der sozialwissenschaftlichen Datenanalyse*, Wolf C, Best H (eds.) Springer, 2010, pp 607–638.
 - 19) Medeiros FV, Vieira A, Carregaro RL, et al.: Skinfold thickness affects the isometric knee extension torque evoked by Neuromuscular Electrical Stimulation. *Braz J Phys Ther*, 2015, 19: 466–472. [[Medline](#)] [[CrossRef](#)]
 - 20) Miller MG, Cheatham CC, Holcomb WR, et al.: Subcutaneous tissue thickness alters the effect of NMES. *J Sport Rehabil*, 2008, 17: 68–75. [[Medline](#)] [[CrossRef](#)]
 - 21) Carter JE: The somatotypes of athletes—a review. *Hum Biol*, 1970, 42: 535–569. [[Medline](#)]
 - 22) Miyatani M, Kanehisa H, Masuo Y, et al.: Validity of estimating limb muscle volume by bioelectrical impedance. *J Appl Physiol* 1985, 2001, 91: 386–394. [[Medline](#)] [[CrossRef](#)]
 - 23) Kaniakakis J: Anatomy, histology and immunohistochemistry of normal human skin. *Eur J Dermatol*, 2002, 12: 390–399, quiz 400–401. [[Medline](#)]
 - 24) Schmelz M: Itch Processing in the Skin. *Front Med (Lausanne)*, 2019, 6: 167. [[Medline](#)] [[CrossRef](#)]
 - 25) Han L, Ma C, Liu Q, et al.: A subpopulation of nociceptors specifically linked to itch. *Nat Neurosci*, 2013, 16: 174–182. [[Medline](#)] [[CrossRef](#)]
 - 26) Petrofsky JS, Suh HJ, Gunda S, et al.: Interrelationships between body fat and skin blood flow and the current required for electrical stimulation of human muscle. *Med Eng Phys*, 2008, 30: 931–936. [[Medline](#)] [[CrossRef](#)]