The influence of electrical muscle stimulation for diabetic foot ulcers:

Key words:

- *Diabetic foot ulcer*
- *Electrical muscle stimulation (EMS)*
- *Nitric Oxide*
- *Veinoplus Arterial*

Background: A decrease in blood circulation in diabetic foot ulcers (DFU) leads to a reduction in the angiogenesis process, macrophages function, neutrophils, and growth factors, which in turn slow the healing process. However, electrical muscle stimulation (EMS) can be used to stimulate the muscle that leads to the lower limbs, increasing local blood circulation. **Aim**: This study was conducted to identify changes in the ABI and the wound development score following EMS in DFUs. **Methods**: We used sequential sampling of respondents who met the inclusion criteria. The control group received standard wound care, while the intervention group received standard wound care plus EMS therapy. EMS intervention was performed for 4 weeks for 30 minutes per day. **Result**: The intervention group that received standard wound care plus the EMS had better-wound healing than the group that only received standard wound care. **Conclusion**: EMS can increase nitric oxide, which causes vasodilation of the blood vessels and stimulates cell synthesis and migration to the wound area.

***Sukarni** is a lecturer in the Department of Nursing Education, University of Tanjungpura, Pontianak, West Kalimantan, Indonesia; **Hikmat Permana** is an Internist of Hasan Sadikin Hospital Bandung, West Java; **Chandra Isabella** is a lecturer in the Department of Nursing Education, University of Padjadjaran, Bandung, West Java, Indonesia*

Diabetes mellitus is caused by the disruption of glucose transport from the bloodstream into the cells, which can lead to the development of micro- and macrovascular complications due to these high blood glucose concentrations (Black and Hawks, 2009). A major complication of diabetes are diabetic foot ulcers (DFU; Price and Wilson, 2007), an wound on the skin accompanied by local dead tissues (Sussman and Jensen, 2012). About 1.3% of the patients suffering from a DFU have circulatory problems, 1.0% have gangrene, and 0.7% required an amputation (Soewondo et al, 2010).

Persistent or chronic hypoxia inhibits wounds healing, by impairing angiogenesis, lowering macrophage function, and an allowing an increase in the number of bacteria in wounds (Bishop, 2008; Rodriguez et al, 2008). This hypoxia is due to the effect of metabolic events on endothelial cells, decreasing nitric oxide (NO). Endothelial nitric oxide synthase (eNOS) produces NO through oxidation of L-arginine's terminal guanidine nitrogen (Tabit et al, 2010). The bioavailability of NO is a major marker for the health of blood vessels (Tabit et al, 2010; Kolluru et al, 2012).

Electrical muscle stimulation (EMS), can be performed by using the arterial Veinoplus tool, developed by Ad Rem in Paris, France in 2010 *(Figure 1)*. This EMS is powered by a 9V battery and provides a local, low-frequency, low-voltage stimulus. The input power is set to less than 0.5W and the power output to less than 0.05W, the wave is modulated in a special pattern, resulting in muscle contraction that ranges between 2–120 beats/minute. Furthermore, it is recommended to use this instrument in situations where blood flow to the lower limbs is decreased. It is designed to improve local blood circulation, which ultimately reduces leg pain and swelling. The improved blood circulation to the lower limbs can improve the ulcers healing in the lower limbs (Veinoplus, 2012).

EMS provides a local frequency that stimulates the contraction of the calf muscles down to the tip of the foot *(Figure 2)*. This contraction can improve blood circulation in the lower extremities that can facilitate the wound healing. The stimulation of muscle contraction

Figure 1. The electrical muscle stimulation (EMS; Veinoplus arterial device)

Figure 2. Application of electrical muscle stimulation (EMS)

by the EMS tool may improve blood circulation by the shear stress, a haemodynamic force on the surface of endothelial cells, which is modulated by the strength of vascular tone (Harrison et al, 2006). The other effect of administering EMS is the migration of the cells into the affected area of the wound. The result of the electrical stimulation or the flow of an electricial charge over the ulcer area is associated with cell migration (Kloth, 2005). The cells that migrate to the anodes and cathodes include macrophages, neutrophils, fibroblasts, myofibroblasts, keratinocytes, and epidermal (Kloth, 2005). Subsequently, the cell's migrations into the area of the ulcer facilitates wound healing.

Aim

This study was designed to identify changes in circulation and the development of diabetic foot ulcers.

Methods

This study has been ethically approved by the Padjadjaran University Ethics Commission with the number 554/UN6.C2.1.2/KEPK/PN/2014.

A sequential sampling method was used to select participants who met the inclusion criteria, they were randomly divided into two groups (control and intervention) and were subjected to a pre-test and a post-test. The control group was treated with standard wound care, while the intervention group had standard wound care plus EMS. Standard wound care involved washing the wound using normal saline, debridement (sharp and autolytic), and the use of dressings materials such as honey, sorbach, silver, alginate, with a secondary foam or gauze dressing .

The inclusion criteria include an ankle brachial index between 0.5 to 0.99, wound in the stage of proliferation >7 days, no infection in the wound area, and the willingness of the participant to seek treatment regularly from Kitamura Clinic Pontianak during the period of a four-week study. The exclusion critrea included foot ulcers with malignancy, cellulitis, ulcers with signs of infection, and pregnancy. People taking medications that contain glucocorticoids, non-steroidal anti-inflammatory and chemotherapeutic substances, as well as patients with a heart-pacemaker were excluded.

The development of the leg ulcers was assessed by using the Leg Ulcer Measurement Tool (LUMT; Woodbury et al, 2004). This process comprises 17 items and has a total score range from 0 to 68. The validity of LUMT is 0.82, and the inter-rater reliability is >0.75, with high sensitivity.

In the control group, the participants received treatment according to the standard wound care set by Kitamura Clinic. The standard of wound care is washing the wound using normal saline, debridement (sharp and autolytic), and the use of dressings materials such as honey, sorbact,

Table 1. Characteristics of participants

Variable	Category	Control		Intervention		*p*
		n	%	n	%	
Sex	Male	9	56.3	7	43.8	0.48
	Female	7	43.8	9	56.3	
Smoking History	Never	8	50.0	11	68	0.94
	Still active	4	25.0	4	25.0	
	Used to	4	25.0	1	6.3	
Wound History	Ever	7	43.8	10	62.5	0.28
	Never	9	56.3	6	37.5	
DFU Grade	2	7	43.8	12	75.0	0.41
	3	5	31.3	4	25.0	
	4	4	25.0	-	-	

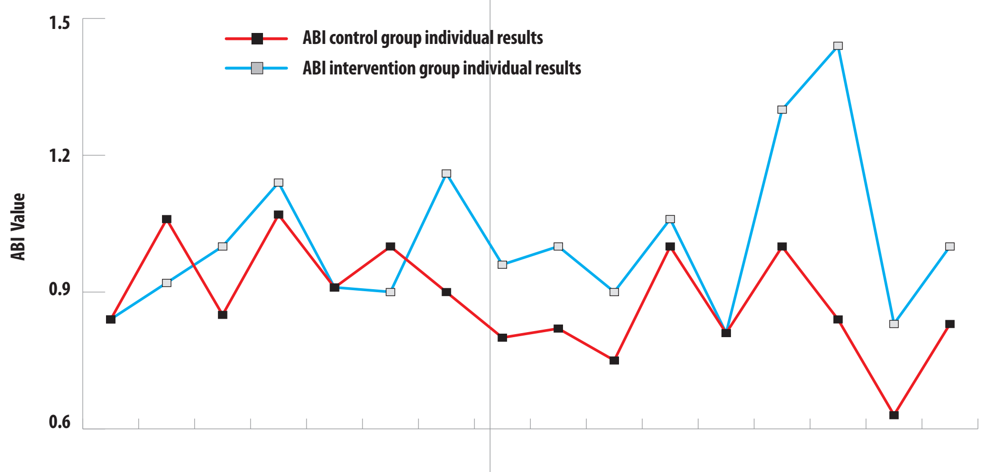
Table 2. Characteristic of respondents

Variable	Control (n=16) mean ± standard deviation (SD)	Intervention (n=16) mean ± SD	*p-value*
Age	53.63±8.09 years	54.25±6.90 years	0.45
Diabetes duration	7.68±5.62 years	7.41±5.43 years	0.88
Ulcers length	4.83±3.23 weeks	5.06±4.50 weeks	0.78
RBG (Random Blood Glucose)	185.69±58.28 mg/dl	210.56±50.22 mg/dl	0.06
Albumin	2.85±0.65 g/dl	2.88±0.49 g/dl	0.90

Table 3. The difference of ABI values between intervention (n=16) and control (n=16) groups

Variable	Group	Mean ± SD	*p*-value
Before	Intervention Control	0.80±0.110 0.85±0.067	0.16
After	Intervention Control	1.01±0.171 0.88±0.119	0.02

Figure 1. ABI value in the intervention and control groups



silver, alginate, and secondary with foam or gauze. In the intervention group particpants first received standard wound care, followed by EMS treatment. The EMS was performed for 30 minutes every day for four weeks and has an intensity or force of contraction ranging between 0 and 50. The power of contraction in each participant varied depending on their level of ability to feel it. After four weeks of treatment, an assessment and re-measurement of the wound development score was conducted. Subsequently, the rescoring development of vascularisation status either in the intervention group or in the control group was carried out after four weeks of treatment. The bivariant-test was conducted to compare the differences between the average value of ABI and the development of the score of the wound by t-test, Wilcoxon, and Mann Whitney.

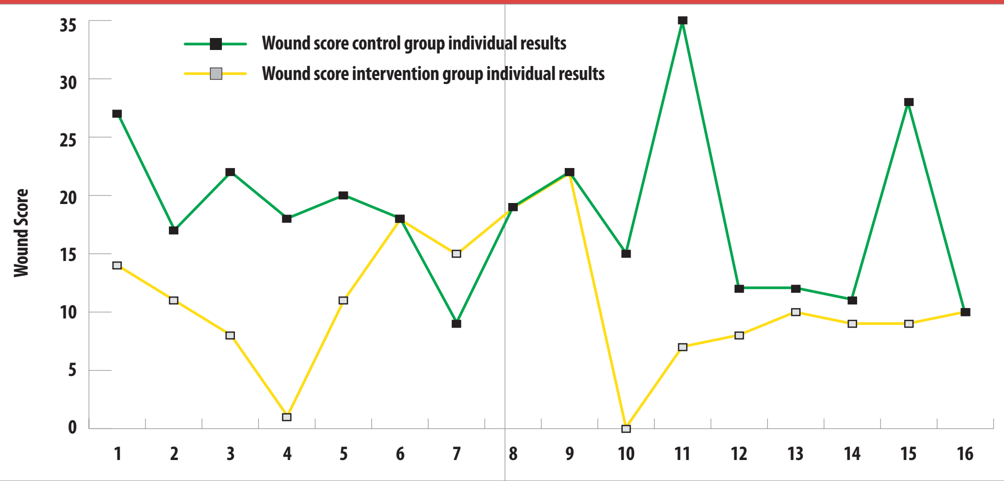
Results

We recruited 32 particpants, 16 to the control group and 16 to the EMS group. Both male and female participants had similar level for each variable assessed in the table (>50%). For instance, more than half of the participants male and female (59.4%) never smoke. As for wound history, the highest number of participants who had suffered wounds before the treatment was about 53.1%, and the 2nd grade of DFU possessed by about 59.4% out of the total participants, and more than half of the participants as well *(Table 1)*.

The participants in the control group had an average age of approximately 53.3 years and differed less than the average age of the participants in the intervention group *(Table 2)*. The duration of the diabetes, the control group was approximately 7.41 years, similarly, to the intervention group, the participants suffered from DM for an average of 7.41 years *(Table 2)*. However, there was a considerable, but non-significant, difference in the duration of the ulcer between the control group participants and the intervention group *(Table 2)*. The temporary blood sugar in the control group

Table 3. The Wound Development Score Differences between control (n=16) and intervention (n=16) groups			
Variable	**Group**	**Mean ± standard deviation**	***p-value***
Before	Intervention Control	27.63±8.951 27.25±9.504	0.909
After	Intervention Control	10.75±5.905 18.44±7.211	0.003

Figure 2. Wound scores in the intervention and control groups



was normal on average, while it was high on average in the intervention group *(Table 2)*. Albumin, in this regard, was at an average low for the control group and intervention group *(Table 2)*.

EMS therapy with standard wound care therapy effectively improved ABI indicating improved circulation compared with the control group *(Table 3, Figure 1)*.

EMS therapy also showed a significant reduction in the wound development scores compared with the control group (*Table 4, Figure 2*). The difference in the decreasing scores of ulcer development in control and intervention groups resulted in the statistical test of p=0.003. This value indicated that EMS therapy was more effective in lowering the ulcer development scores compared with the control group.

Discussion

Circulation

EMS is a stimulator that provides low local frequency and intense voltage stimuli. Stimulating muscle contraction is a method to increase the blood circulation in the limbs' area and improve patients' walking ability (Veinoplus, 2012). Furthermore, EMS generates pulsate frictional forces, a hemodynamic force on the surface of endothelial cells that modulates cell activity, including regulation of vascular tone and inflammatory responses (Kolluru et al, 2010). This leads to an increase in NO production and then stimulates the vasodilatation of blood vessels and leading to increased blood circulation. In patients with diabetes, there is a decrease in the shear stress caused by the blood, this leads to a disturbance in the blood circulation in the lower extremities. Shear stress in blood vessels produced by EMS can affect and activate eNOS pathways, NO production.

Under normal circumstances, the shear stress stimulates the blood vessels, especially in the endothelial layer, to dilate (Kolluru et al, 2010). The increase in the ABI value after EMS treatment becomes an indication of increased blood circulation to the endothelial layers of the blood vessels, as it was previously explained that the critical role of NO lies in the vasodilation of the blood vessels. Another essential mechanism is vascular endothelial growth factor (VEGF; Dela Paz et al, 2012), a vasoactive substance that is released by the endothelial cells. This growth factor plays an essential role in ulcer healing that is carried out through some processes such as angiogenesis, collagen deposition, and epithelialisation (Bao et al, 2010).

Wound development

The use of electrical stimulation can increase the production of fibroblasts, migration of cells with various types of cells such as macrophages, neutrophils, myofibroblasts, keratinocytes, and epidermal cells in the wound area thereby increasing the process of tissue repair in the wound. Electrical stimulation then triggers angiogenesis and ulcers tissue oxygenation, increases autolysis and blood circulation in the cutaneous tissue, as well as the return venous pressure in the legs, and reduces the number of bacteria as well as the pain (Kloth, 2005; Chapman-Jones et al, 2010). Furthermore, the application of EMS in wound care enhances the migration of cells to the wound area. Electrodes given through EMS make free electrons direct the flow of electricity which functions to distribute cells that support the process of tissue repair and accelerate wound healing. With one-way current direction (DC) and monophasic, two polarised electrodes relate to one another, where one is negative (cathode), and the other is positively charged (anode). The negative ions move to the anode while the positive ions move to the cathode (Chadwick et al, 2013)

Cells that play a role in the healing process rely on certain stages of wound healing such as macrophages, neutrophils (inflammation), fibroblast (proliferation), and myofibroblast, keratinocytes, and epidermal (remodelling). Macrophages, neutrophils and epidermal cells migrate to the anode. Neutrophils migrate towards both anode and cathode, while leukocytes, fibroblasts, myofibroblast and keratinoid move toward the cathode. The cells-migration occurring in the ulcer area will aid the wounds in restoring the tissue in such a way that the healing of wounds can be accelerated (Clark, 2013).

Oxygen is essential for leukocytes to destroy bacteria and fibroblasts in stimulating collagen. Resistance to bacterial infections in the ulcers depends on neutrophils, neutrophils modify oxygen molecules to high-energised radicals. Moreover, the lack of oxygen can inhibit phagocytosis activity (Sussman and Jensen, 2012).

A previous study reported that the use of EMS every day with a short pulse and asymmetrical biphasic wave effectively promoted wound healing in patients with diabetes, as well as reducing infections caused by bacteria, improving the local perfusion of ulcers, and accelerate the healing of the ulcer (Thakral et al, 2013).

Limitation

The implementation of EMS therapy cannot be carried out at the same time every day, this is related to the non-permanent time of the respondent's visit to the clinic for various reasons. The confidential factor, which is uncontrollable in this study is psychological conditions such as stress and depression. The psychological conditions are difficult to be controlled. Further studies are needed to examine the relationship between the effects of stress on the healing of diabetic foot wounds during EMS therapy.

Conclusions

The use of EMS is more effective in improving circulation and accelerates the healing of DFUs. The results can be used as an evidence-based practice for the development of wound care science, and EMS therapy can be used as an adjunct therapy for patients who experience circulatory disorders following the standard therapy protocol. Further study on the development of concepts and research related to additional treatments in wound care is needed. It is necessary to conduct further studies on the use of EMS against the healing of diabetic foot wounds with larger samples and tighter sample control and the same time during the therapy process. WAS

Declaration of interest:

All authors declared no conflict of interest. No funding was received.

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