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Design and Manufacturing an Electrical-Bandage Device for Speed up Wound Healing

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Abstract: Background: Chronic wounds considered a serious condition to patients and healthcare subjects worldwide. **Subjects and methods**: Present study designed a device used to treat the wounds by using electrical stimulation (ES) with high voltage pulsed current (HVPC) that encompasses many circuits including boost converter, H-bridge, and microcontroller. Case control and case report studies, enrolled ten male wild type rabbits as well as diabetic woman. After applying HVPC (20V-38v) of voltage, 100 pps of pulse frequency, 100µs of pulse duration) one time/day. **Results**: Designed treatment revealed efficient healing of wounds by using the HVPC model. **Conclusion**: the designed E bandage can be used to enhance the healing of wounds in diabetic and non-diabetic patients.

Key words: Electrical stimulation, High voltage pulse current, Electrical bandage , HVPC, ES, E-bandage.

Introduction

Chronic wounds are affecting about 5.7–6.5 million individuals worldwide and a great cost was estimated annually [1]. Researchers have begun to study many methods in order to improve wound healing, including the use of dermal skin substitutes, antibiotics, pressurized oxygen, antiseptics, as well as physiotherapy such as electrical stimulation (ES) [2]. Different forms of ES have been used to cure complicated wounds; there direct effects of ES include inhibition of bacterial growth, support of the immune system and block the reproduction of bacteria. Indirect effects include accelerated wound healing and increased perfusion [3]. The ES contributes

of healing by enhancement of the emigration of macrophages, lymphocytes, keratinocytes, macrophages, and fibroblasts, increasing the oxygen concentration of blood around the wound and wound stretchy [4], There are many methods of treatment for chronic wounds including; ultrasound, electrical stimulation, wound dressings, compression bandaging, debridement, and negative pressure of skin substitute therapy Figure(1)[5].

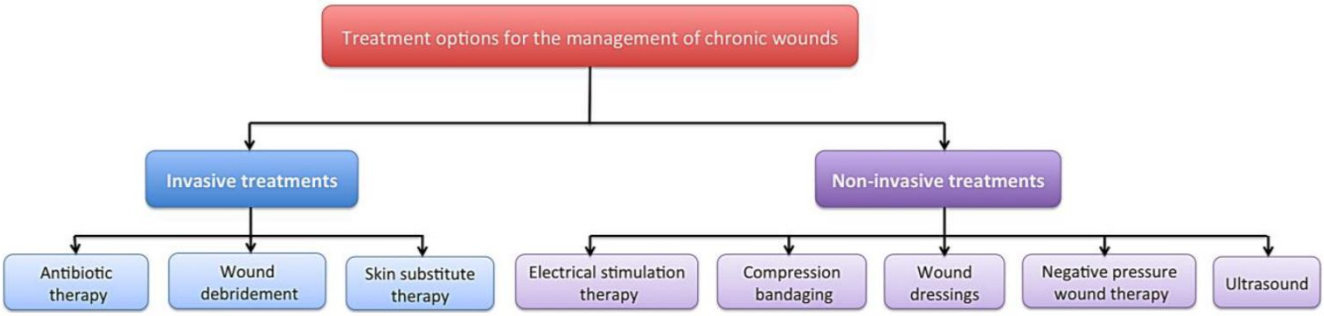

Figure (1): Strategies of wound treatment**.**

An electrical bandage (E-bandage) is a simple and non-invasive device that uses an electrical field that stimulates wounds healing by contributing to disrupting bacterial growth and activate of migration, proliferation, and differentiation of fibroblasts by using electrodes applied in the wound tissue as shown in Figure (2). The human body has a bioelectric system known as endogenous which make electrochemical signals in several Regions, like the bone, skin, brain, and muscle tissues. The current transported by charged ions over the tissues, asymmetrical ionic flows produces electrical potentials. The current known as skin battery is produced by the movement of ions by the Na+/K+ pumps of the epidermis, When skin is injured negative polarity is created in the center of the injury area and positive in the edge [7].

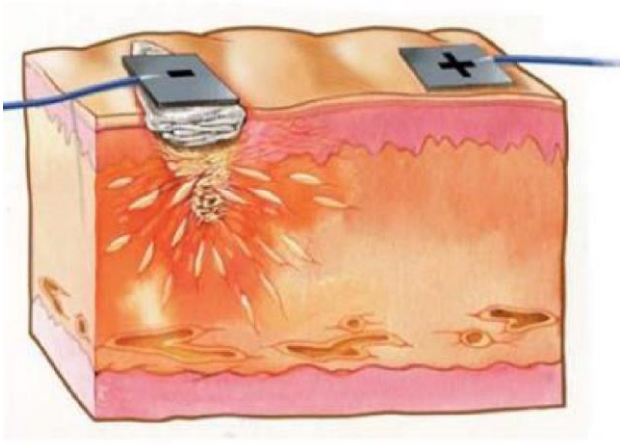

Figure (2): Applied electrodes on skin wound [6].

Material and Methods

Subjects:

At present case-control study E-bandage had been designed to test their effectiveness on wound healing.

We used 2 groups of male wild-type rabbits (5 as cases, and 5 as control) of 1-1.22 kg (6-week age). Around 1 cm circular wound of rabbit skin was made in the left-back lateral of each case and control animals

as shown in figure(3), we applied the electrodes of E-bandage (HVPC) from day 1 to day 8 (one time/day for 45-60 minutes).

Figure (3): Circular wound of studied animals.

The module High Voltage Pulsed Current (HVPC) which encompasses different modules including boost converter, H-bridge, and microcontroller circuit as shown in figure (4) , was designed to provide a high changeable pulse voltage adjusted by a potentiometer to achieve the safety of the case also to provide an efficient range of therapy and a pulse signal interruption controlled by microcontroller ESP as shown in figure (5).

Application of E-bandage device was applied 8 days on wound of cases animals 1 time/day (40-60 minutes) and the voltage ranged from 20-40 volts.

The HVPC Schematic block diagram circuit component as shown in figure(6) module of HVPC consists of:

- Battery (3.7V, 600 mAh)
- Boost Converter (LT1171)
- Potential Resistance
- Current sensor (INA219 DC)
- NodeMCU ESP8266
- H-bridge Circuit (L298N)
- Electrode
- Resistances, capacitors and diodes

There are three main circuits of HVPC modules including

1- Boost converter circuit: The E-Bandage device includes a boost converter (LT1171) circuit to transform input battery voltage from 3.7V 600mAH to a maximum of 38V dc. The output voltage is controlled by a potentiometer.

2- Microcontroller Unit: The Microcontroller NodeMCU ESP8266 being the brain of the E-bandage that controls the pulse frequency and pulse duration to be delivered to the skin. The microcontroller also received the magnitude of voltage and current from the Current sensor (INA219 DC) and Displays on the OLED SSD1306 Display.

3- H-bridge circuit: The main function of this circuit is to operate pulse generation using chip L298N which received pulse frequency and pulse duration from ESP. H-bridge and microcontroller Unit Contribute to converting the output dc voltage of boost converter (LT1171) to pulse voltage. The H-bridge circuit is connected to four diodes, these diodes are connected to two electrodes and transmitted single to the skin of the case.

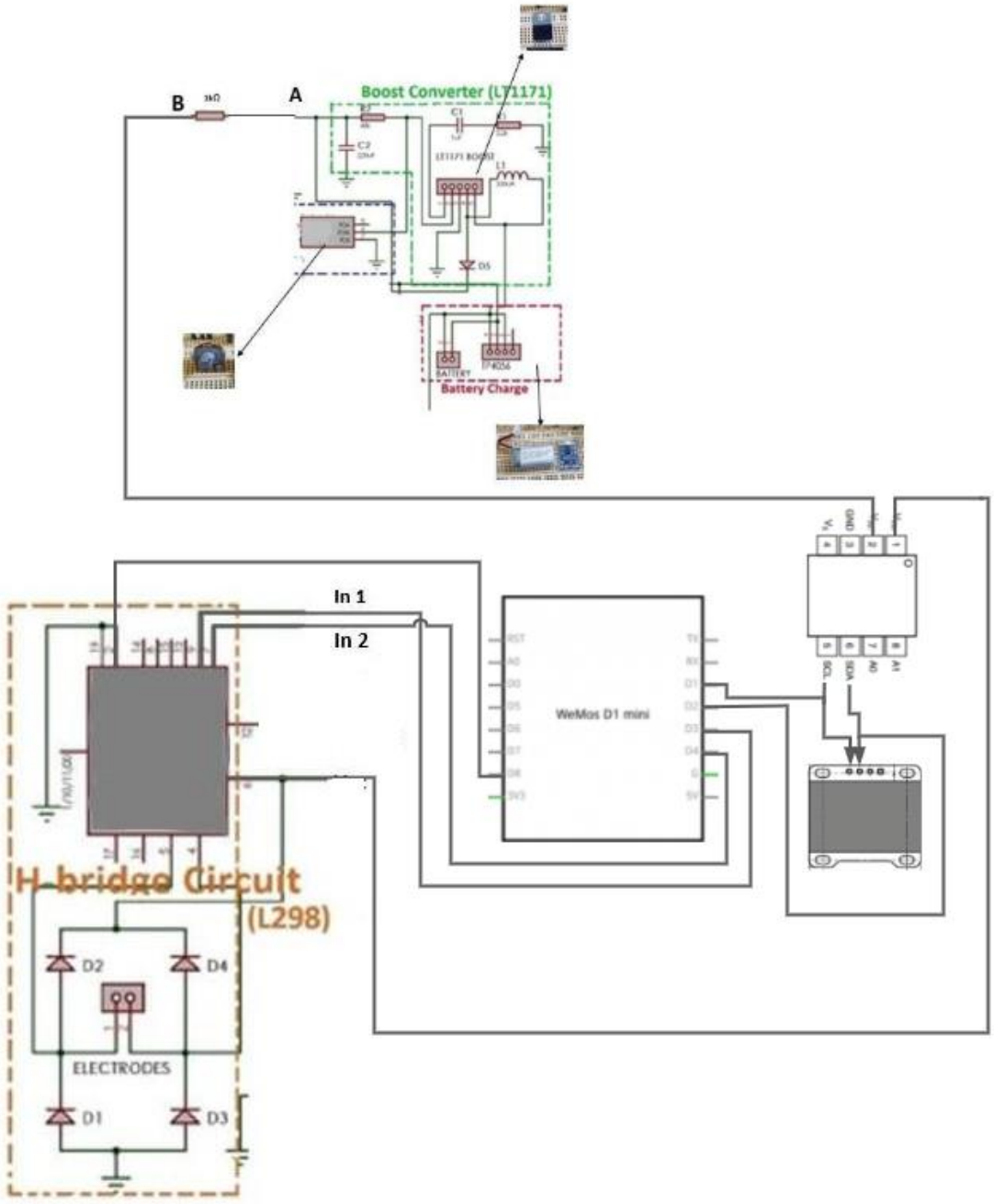

Figure (4): The Circuit Diagram for the High voltage pulse current Module.

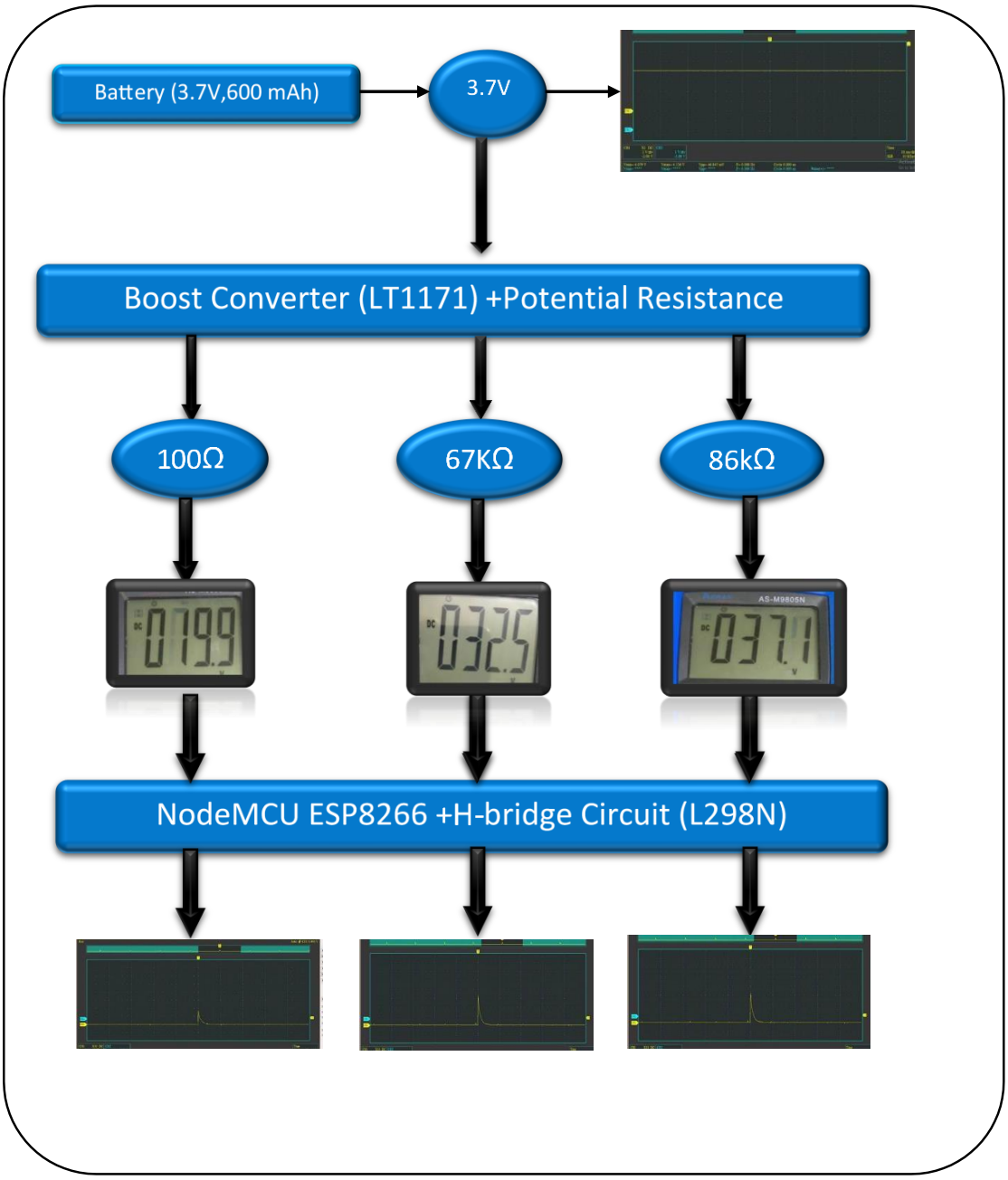

Figure (5): Shown signal processing from input to output.

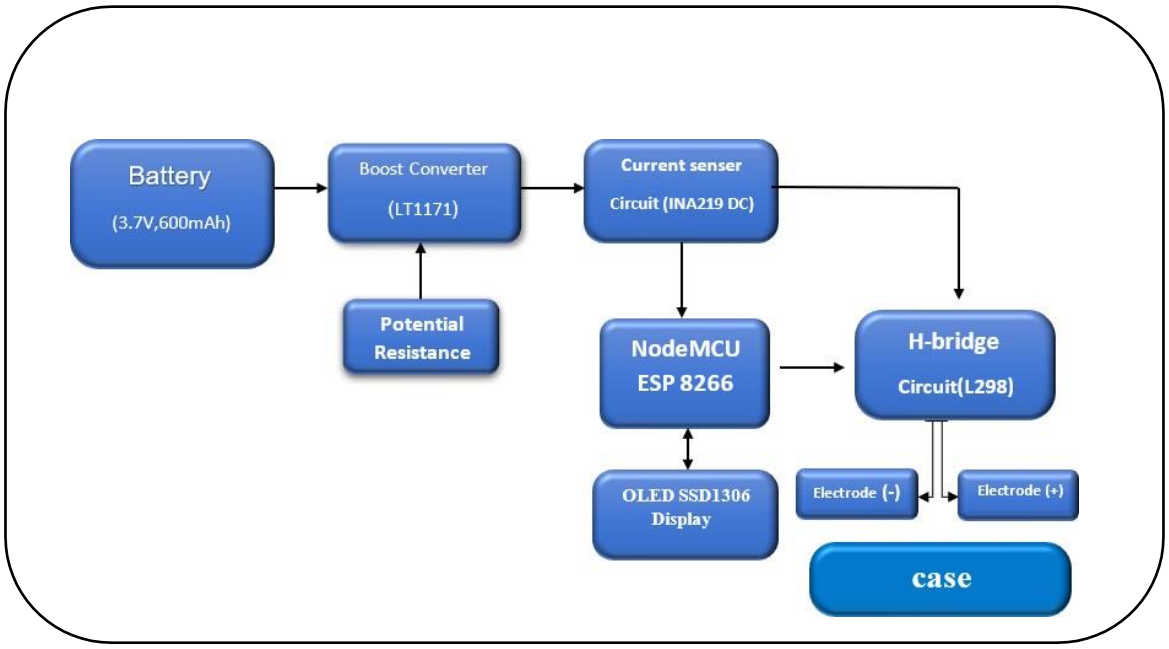

Figure (6): Schematic block diagram of HVPC.

Statistical analysis

Statistical Packages for Social Sciences (version 25) and Microsoft Office Excel (2013) were used. We used One Way Analysis of Variance (ANOVA) to assay of difference among studied groups. The results were presented in form of mean±standard deviation (M±SD). The statistical significances were considered when $p \leq 0.05$.

Results and Discussion

Although, the results of current study revealed significant developments (p value<0.05) in wound healing in both of cases and control groups along with time, but treated wounds with E-Bandage of cases animals showed significant (p value<0.05) stimulation toward wound healing compared to untreated control animals (table:1 , figure: 8)

Table (1): Diameters (mm) of wounds in studied groups along with time.

	Cases	**P value (Sig≤0.05)**				**Control**	**P value (Sig≤0.05)**			
	M±SD	Day2	Day 4	Day 6	Day 8	M±SD	Day 2	Day 4	Day 6	Day 8
Day 0	10±0	<0.001	<0.001	<0.001	<0.001	10±0	<0.001	<0.001	<0.001	<0.001
Day 2	6.33±0.68		0.04	<0.001	<0.001	7.7±0.65		0.01	<0.001	<0.001
Day 4	5.33±0.55			0.001	<0.001	6.33±0.51			0.001	<0.001
Day 6	3.33±0.65				<0.001	4.33±0.55				<0.001
Day 8	0.33±0.08					1.66±0.31				

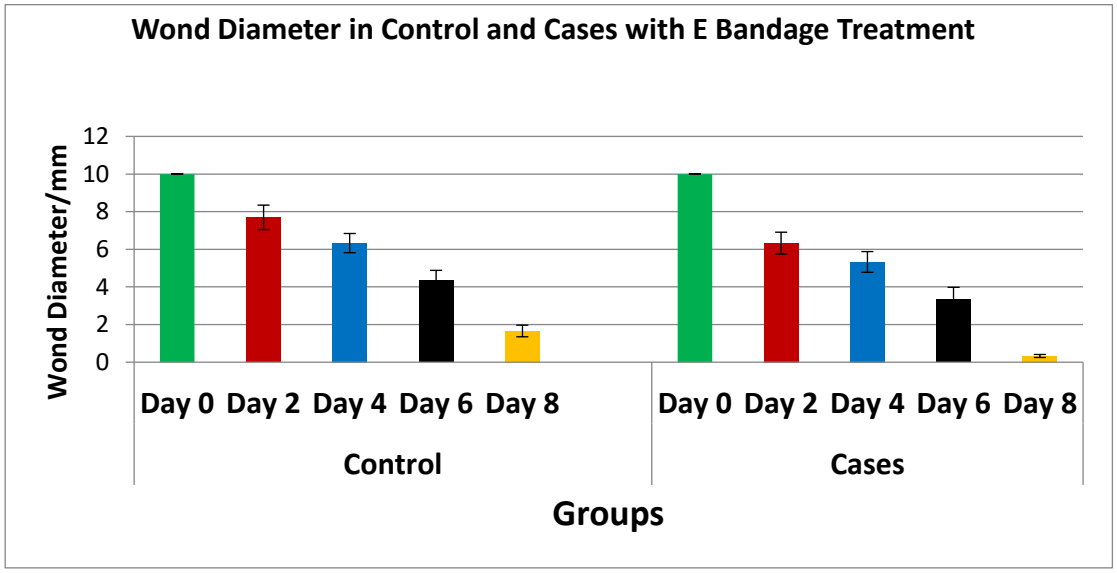

Figure (8): Showed the Diameters (mm) of wounds in studied groups along with time.

From the beginning of the wounds in both of studied groups of animals, the healing process began in both of them and the wound contraction in the lower layer of skin begins to be clear at the day 3 (HVPC=20V) in the case of the animals while wound contraction in the control animals were slower compared to the case animals, such contraction in the treated animal with HVPC becomes more obvious and more developed through the 3-8 days particularly after increasing the HVPC voltage to 38V as shown in table (2).

Table (2): Summary of the variable factors in the study Animals.

Treatment day	magnitude of output voltage	polarity	Treatment duration
1-3 day	20V	Negative	45 min
3-6 day	38V	Negative	60 min
6-8 day	38V	Positive	60 min

From the results that were obtained, the positive effect of treatment using HVPC appears clearly, which gave excellent results in stimulating the acceleration of wound healing in general, but in particular, the stimulation process became more effective and efficient when the voltage was raised from 20V to 38V.

Clinical sample:

The clinical specimen in whom electrostimulation HVPC therapy was applied to stimulate wound healing for 3 days as shown in table(3) with HVPC (38Vof voltage, 100 pps of pulse frequency, 100μs of pulse duration).

Table (3): Summary of the variable factors in the study Clinical sample.

Treatment day	magnitude of output voltage	polarity	Treatment duration
1 day	30V	Negative	45 min
2 days	38V	Negative	60 min
3 days	38V	Positive	60 min

The device was used to stimulate the healing of an acute wound in the hand of a woman with type 2 diabetes who had a deep wound in her hand with a length of 7mm. The results of stimulating the healing of the

mentioned wound for three days showed the progression of healing by reducing the length of the wound from 7mm to 3mm.

Discussion:

Indeed, wounds with chronic inflammation are considered one of the major exacerbations of many diseases including diabetes mellitus, these lesions resort to long-term of negative effects on the health patient's. Long duration of hyperglycemia condition leading to physiologic dysfunction including wound healing process which may lead to elevation of reactive oxygen species. Furthermore, it is widely appreciated to disturb of angiogenesis, insufficient circulation, as well as dysfunctional cells endothelium regarding to migration as well as proliferation leading to impair repair of wounds in diabetic patients [8]. Intact capillary blood vessels network is substantial delivery of nutrients, oxygen, as well as growth factors which required for excellent healing of wounds[9]. The methods which stimulate neovascularization as well as modulate the hypoxic microenvironment are highly efficient for healing of diabetic wounds. Cure of wounds related to efficient cellular proliferation, differentiation, migration, as well as secretory function. Migration of Cells to the wound location by chemotaxis and/or electro taxis consider the former cascade in wound healing; those processes authorize cells to be mobile into location in order to support their proliferation and differentiation [10]. Rapid as well as constant migration of inflammatory cells across the wound is a substantial first step of wound-healing manner. The usage that mimics endogenous electric field excitation is considered a hopeful fashion in healing of diabetic wounds. A microenvironment which supports cell migration and a conventional means that is able to be used to apply electric field stimulation is also required. As such, hypothesized that the incorporation of electric field stimulation and Chitosan-Vaseline gauze might support wound-healing cases. Former researchers have focused fundamentally on the role of electric field excitation and their function in promoting wound healing. Furthermore, the electric field stimulation devices currently in clinical usage were big and not proper to patients [11, 12–15].

Wound bandages are usually used to treat wounds as they preserve a perfect wound milieu that plays a substantial role in healing status of wounds [16]. It is important to be sure that the agents of wound milieu, including microorganisms, pH, humidity, can affect healing steps because they are all concerning as well as can impact each other [17]. Furthermore, Bacterial contaminated wounds appear to change pH, and proinflammatory cytokines production factors, conservation the wound stuck in self-perpetuating inflammatory processes [17, 18].

Our results indicated that E-bandage of HVPC technique was an effective design to support healing of wounds; present results are consent with the findings of other studies [19]. One cause is that high-voltage current, probably prominent to low-voltage running may relate to its ability to further penetration[20]. Other case control studies, were found that, in compared to controls, treated wounds with HVMPC expressed elevated levels of vascular endothelial factor, which is substantial agent for stimulation of angiogenesis [21,22]; result in our estimation that HVMPC maybe stimulate wound healing by accelerating process of angiogenesis. Indeed, HVMPC technique application caused an increase of blood vessels number at wound sites in compared to the wounds of the control group.

Conclusion:

In this study, we have fixed HVPC technique as an effectively agent that maybe used in ES management for the treatment of wounds of diabetic, so we lock for design of such device for traditional distribution.

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