Microcurrent as an adjunct therapy to accelerate chronic wound healing and reduce patient pain

Objective: The primary aim is to assess the efficacy of microcurrent, a form of electrical stimulation, as an adjunct therapy in accelerating healing in chronic wounds by reducing wound size and pain level. The secondary aim is to assess the qualitative changes in these parameters: inflammatory symptoms, vasodilation, sleep quality, gait and frequency of bowel movement.

Method: Eligible patients with chronic wounds were enrolled between March and June 2016, from the Wound Care Unit, Hospital Kuala Lumpur in this consecutive case series. Standard wound care was performed with microcurrent as an adjunct therapy. Each patient was treated with an anti-inflammatory frequency, followed by a vasodilation frequency, while having their wounds cleansed during each dressing change. Patients were loaned a home-microcurrent device to treat themselves three times daily using a tissue repair frequency for four weeks.

Results: A total of 100 patients with chronic wounds, such as diabetic foot ulcers, venous leg ulcers, and pressure ulcers, were recruited. During the four-week treatment period, all patients had a reduction in wound size, with 16 having complete wound closure. All 89 of the 100 patients who complained of pain, associated with their wound, experienced reduced pain scores, with 11 being pain-free at the end of the four-week period. There was significant reduction ($p<0.001$) in both mean pain score and mean wound area during the treatment period, as well as improvements in other parameters, such as reduction in inflammatory symptoms (leg swelling, foot stiffness), increased vasodilation (skin discolouration, leg heaviness, early morning erection, sensation), improvement in sleep quality, gait, and frequency of bowel movement. No adverse events were reported.

Conclusion: The results of this study show there was significant reduction in wound area and pain score during the treatment period. The ease of use of microcurrent devices would advocate its use in accelerating wound healing

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adjunct therapy • chronic wound • electrical stimulation • electromedicine • microcurrent • pain reduction • vasodilation

Chronic wounds not only have a physical impact, they are also a major problem in terms of their social and psychological impact on patients.[1] They can have an adverse effect on health-related quality of life (HRQoL) items such as, levels of pain, restricted mobility, sleep quality, physical function (i.e., levels of physical energy and ability to carry out daily living activities), psychological wellbeing (i.e., stress, is one factor that can lead to poor bowel movement,[2] depression, anxiety and fear); social functioning (i.e., ability to engage in meaningful, interpersonal relationships), and somatic sensation (i.e., disease-related symptoms such as wound pain).[3–5]

Microcurrent therapy

Electromedicine, the use of electrical energy in medical diagnosis and treatment, has been used in the field of medicine for centuries.[6] Clinical studies have reported positive results on wound healing using electrical stimulation, and it has been used in clinical practice to accelerate wound closure.[7,8]

Microcurrent therapy is a particular form of electrical stimulation. Microcurrent is an electrical current that is in the microampere (μA) range, or one-millionth (10^{-6}) of an ampere, and is below the sensation threshold. This form of minute pulsating current mimics the currents generated in the body at the cellular level, and is known to stimulate cellular physiology and growth.[9–12] As a consequence, microcurrent can penetrate the cells, unlike other electrical stimulation devices which bypass the cells to focus on muscle, tissue and fascia.[13] This may be favourable where endogenous healing has failed.

It has been theorised that healthy tissue is the result of the direct flow of electrical current throughout the body.[14] Electrical balance is disrupted when the body is injured at a particular site, causing the electrical current to change course and lose the ability to communicate with the rest of the body. Microcurrent therapy realigns the flow and aids in tissue repair.[10] Each cell in the body has its own specific frequency, which may be disrupted by injury or disease.[9] Microcurrent therapy simply restores the normal frequencies within the cells, resulting in improvements in inflammation and function.[9]

Studies have shown that electrical stimulation aids in the healing of wounds.[15–17] According to Foulds et al.

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an uninjured (intact) skin epidermis has a transepithelial potential (TEP) difference of 10–60mV. TEP is generated from the uneven distribution of sodium ions (Na^+) across the skin.[18] Presence of a wound will damage the intact skin epidermis and disrupt the TEP. The positive ions will move from the intact skin to the edges of the wound and then return to the normal epidermis, thus, forming a loop.[19] The cells in the intact part will then continue the ion transport to the basal layer of the epidermis to maintain the TEP. The strength of the electrical field gradually decreases over time until the wound is covered with epithelial cells.[20] Hence, endogenous electrical stimulation is important in wound healing.[21]

Pulsed electromagnetic field (PEMF) therapy is the application of a magnetic field for therapeutic purposes, delivered using an accessory attached to the microcurrent device. It is effective because it causes cell regeneration by improving enzyme kinetics and repolarising cellular membranes, restoring the body's natural electromagnetic energy.[22] PEMF devices use magnetic fields to generate an electrical field that stimulates the internal electrical and chemical processes by penetrating the cell and stimulating the cell metabolism. The presence of the magnetic force will re-align the damaged cell ions into the correct position, eliminating excess fluid from within the cell. Cell damage will stop and healing of the cells will begin over a period of days.[23]

Research has shown that PEMF is effective in improving circulation, accelerating tissue regeneration, reducing inflammation, regulating the nervous system, relieving pain and reducing wound healing duration.[24–30]

Objectives

The primary objective is to evaluate the efficacy of microcurrent as an adjunct therapy in reducing wound size and pain score in patients with chronic wounds.

The secondary objectives are to assess qualitative changes in:

- Inflammatory symptoms: leg swelling, foot stiffness
- Sleep quality
- Vasodilation: skin discolouration, sensation, leg heaviness, early morning erection
- Gait
- Frequency of bowel movement.

Methods

Study design

A consecutive, observational, case series design was selected as this study involves a particular intervention on subjects having a similar diagnosis, and which, therefore, does not require a control group. We recruited every eligible subject from a clinical setting population until the required sample size is achieved.[31,32] Methods triangulation,[33] a technique which combines both quantitative and qualitative methods, is used to increase the depth of analysis and to minimise biases inherent in any single methodology.[34] Evaluation, assessment and documentation, standard wound care and microcurrent treatments were carried out during the course of the study. Patients were assessed for any clinical signs of wound infection.

Standard wound care was performed with microcurrent treatment as an adjunctive therapy at the wound care clinic. Patients were trained on the usage and care of the home-microcurrent device loaned to them, and were requested to perform microcurrent treatment three times a day at home for four weeks, in between clinic visits for dressing change. Dressings were changed one to three times a week, subject to the clinician's judgment and the needs of the individual patient. Follow-up was done on a weekly basis at the Wound Care Unit, Hospital Kuala Lumpur every week for four weeks. Ad hoc home visits were arranged and patients used a small pocket diary to document treatment frequencies and symptoms experienced.

At baseline evaluation (week zero) during the enrolment process, patient records were reviewed to document demographics, medical history and wound-related data, including aetiology, history, location, frequency of tramadol intake, and wound dimensions.

This study conformed to the guidelines set out in the Declaration of Helsinki for Ethical Principles for Medical Research Involving Human Subjects.[35] The study was approved by the Kuala Lumpur Hospital Review Board (local institutional board). The study objectives and potential risks involved were explained to the patient in detail. Informed consent, and permission to use wound photographs and case details for publication/research purposes was obtained. Participants were advised not to undergo any other electrical stimulation therapy for the duration of the study period.

Devices used in the study

We used two different models of microcurrent device, the BEST non-touch wound care system (BEST, Biofeedback Electro-Stimulation Technology, Avazzia, Inc., US) which comprised of a pulsed electromagnetic field (PEMF) accessory attached to a BEST microcurrent device for clinician use. The distinctive feature of the clinician-use system is that the electromagnetic signal transfers energy 'wirelessly' through air, clothing, bandages, casts, dressing, tissue and other materials, except metal, requiring no contact with skin, thus, minimising the possibility of infection from the instrument.

The BEST home-microcurrent device for patient use consists of a conductive electrode adhesive pad attached to a BEST microcurrent device. The advantage of this home device is that, treatment is delivered via conductive electrode adhesive pads applied on either side of the bandage where there is healthy skin, thus, eliminating the need to open the wound dressing or bandage to deliver stimulation.

These handheld, battery-operated microcurrent devices produce a microcurrent (0–1,200µA) electrical impulses and pulsed high voltage (20–500V), and are able to communicate with the body's nervous system.[36] The device has various modes in the form of pre-set frequency ranges and packets or groups of pulses which are used for a wide range of therapies. The PEMF accessory emits a safe form of electromagnetic pulses (magnetic induction output up to 2,600 milligauss). When attached to the microcurrent device, the PEMF accessory is modulated by frequencies generated from the microcurrent device.

Participants

The study was carried out in an outpatient setting at the Wound Care Unit, Hospital Kuala Lumpur (WCUHKL), Malaysia, where referred patients usually have a greater severity or more advanced illness and greater comorbidity.[37] Study participants comprised of patients who either attended for their routine treatment visits or were referred for treatment to WCUHKL between March and June 2016. Patients were recruited on the basis of the following inclusion criteria:

- Presence of a chronic wound (defined as wounds that fail to heal in an orderly and timely process to produce anatomic and functional integrity, over a period of three months)[38]
- Adults aged 18–90 years old
- All types of wounds, including diabetic foot ulcer (DFU), venous leg ulcer (VLU), pressure ulcer (PU)
- Wound surface area ≥0.5cm^2 and ≤22cm^2
- Able to comply with weekly visits to WCUHKL
- Able to perform microcurrent treatment at home on a daily basis.

These patients had had a full diabetic/arterial assessment, and this observational assessment was formulated to include patients with chronic wounds of a variety of aetiologies.

Patient exclusion criteria included:

- Use of any microcurrent device in the six months before the study
- Presence of an electrical implant, such as pacemaker or neural stimulator
- Low blood pressure
- Malignancies undergoing treatment or any other malignancy (in remission or not) with involvement of the musculoskeletal system.

Clinical intervention

Physical assessment for discolouration, leg swelling, foot stiffness, sensation and gait as well as pain score assessment were carried out and documented pre-microcurrent treatment, and during each dressing change. Participants were then given standard of care by nurse that involved wound assessment, wound bed preparation, debridement, and application of wound dressings, appropriate to the wound aetiology. Participants were assessed for any clinical signs of wound infection that could indicate a rise in the wound's bioburden and account for increased wound pain.

Each participant received the same number of treatments per protocol and had microcurrent therapy delivered while having their wounds cleaned. This therapy was administered by holding or placing the PEMF accessory, set to a pre-set anti-inflammatory frequency, at least an inch (approximately 2.5cm) over the open wound bed for 10 minutes in order to get maximal penetration of the wound in both depth and breadth. This was followed by administration of a pre-set vasodilation frequency for 10 minutes. The strength of the microcurrent device was set to maximum intensity because a stronger magnetic field was required to penetrate deeper into the cells and tissues.[39] Patients were advised to drink at least 500ml of water after each microcurrent treatment as it is known to eliminate waste products and toxins from the body due to lymphatic drainage.[40] A digital photograph of the wound was taken during each dressing change after standard wound treatment.

Post-microcurrent treatment, physical assessment for discolouration, leg swelling, foot stiffness, sensation and gait as well as pain score assessment were carried out and documented, as soon as the therapy was completed.

Home intervention

At home, participants self-administered the microcurrent therapy by attaching the device to a pair of conductive electrode adhesive pads, and applying these to either side of the bandage, over the healthy skin, without the need to remove the bandage or dressing. The setting used with the home-microcurrent device was a pre-set tissue repair frequency. This home-treatment was carried out for 20 minutes per therapy, three times daily. Unlike the treatment at the clinic, the power-level selection key on the microcurrent device was adjusted until only a subtle prickling sensation was felt. Participants were advised to adjust the power level on the device to a bare minimum intensity. This is in accordance with 'Arndt-Shultz Law' which states that a weak stimuli accelerates physiological activity and strong stimuli inhibits or even halts physiological activity.[41]

Assessment tools

Linear wound dimensions (length and width) were measured and documented during each dressing change, using a disposable paper ruler. Wound area was calculated in cm^2. Participants were asked to rate subjectively their pre- and post-microcurrent therapy pain scores, using a 10-point visual analog score (VAS),[42] where a score of zero indicates no pain and a score of 10 indicates the worst pain. At the end of the four-week period, the wound area and pain scores documented over the course of the study, were averaged up for use in analysis.

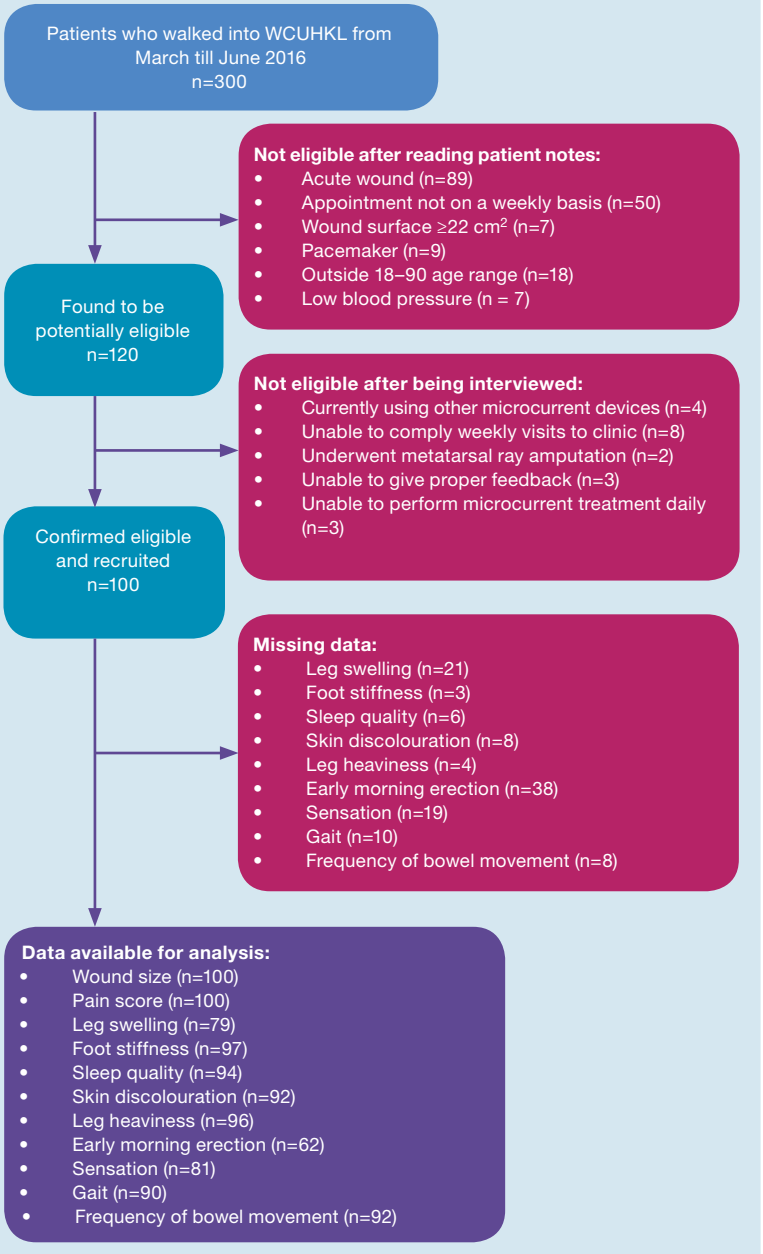
During each dressing change, certain parameters were observed and assessed by the investigator before and after the microcurrent treatment was administered.

On the last day of therapy, participants were asked a set of questions on changes they observed in certain parameters: sleep quality; leg heaviness; early morning erection; and frequency of bowel movement, since the start of the therapy. These parameters were analysed at the end of the four-week period.

Assessment methods included:

- Leg swelling assessment: affected area was marked with a marker. Circumference of the area was measured using a measuring tape before and after microcurrent therapy. This parameter was documented as either 'reduction in swelling', 'no change', or 'increase in swelling' for patients with swollen extremities, and 'no complaint' for patients who did not have swollen extremities
- Foot stiffness assessment: the participant was positioned on the bed which was reclined to about 45°. A pillow was placed under the upper part of the lower legs to flex the knee and lift the heels off the surface of the bed. Ankle movements such as dorsiflexion, plantarflexion, inversion and eversion were assessed and documented[43]
- Skin discolouration assessment: area of normal skin colour was used as a comparison to assess changes in skin discolouration. Digital photography (with flash) was also used to assess improvement in discolouration.
- Gait assessment: the participant's gait was observed and documented when entering (for pre-microcurrent therapy) and leaving (post-microcurrent therapy) the treatment room
- Sensation assessment: cotton (light touch) and neurotip (sharp touch) was used to touch the participant (who had his/her eyes closed) during foot assessment according to the nerve innervation. The participant's reaction was documented.

Fig 1. Flow Diagram for participant recruitment and exclusion



n=number of participants

Potential source of bias

Selection bias will be present in this case series as the participants are selected only from the pool of patients at WCUHKL and therefore may not represent the wider population. However, this bias was addressed by conducting patient selection in a consecutive manner, and identifying inclusion and exclusion criteria for the patient selection process. Consecutive selection of participants also addresses the issue of assessment bias in case series which can result in selective reporting favouring the intervention.[44] Absence of a control group in a case series accounts for observation bias. This has been addressed by having a large sample size for this study (n=100).[45]

Statistical methods

Statistical analysis was carried out by an independent statistician in order to minimise bias. Data was extracted and imported into SPSS Version 20 for Windows (IBM SPSS, Inc., Armonk, NY). Primary objectives were reported as mean±standard deviation (SD). Pair-wise comparisons between pre- and post-microcurrent therapy mean wound area, as well as pre- and post-microcurrent therapy mean pain score were tested with a paired T-test. As a measure of significance, p-values from the test statistic and 95% confidence intervals (CI) of the mean were reported for each of the primary objective groups. A p-value of ≤0.05 determined statistical significance.

Secondary objectives were reported as a response variable %. An analysis of variance (ANOVA) was performed with the following explanatory variables: decrease in leg swelling and heaviness, foot stiffness; increase in discolouration, sleep quality, gait,

sensation, frequency of bowel movement, early morning erection.

'No complaint' was coded as 'missing data' because data was not available. Missing at random (MAR) assumptions were used to address missing data analysis procedures in this case series.[46] In this case series, the issue of missing data was addressed by doing a complete case analysis or listwise deletion and eliminating those sections that did not contain any data.[47] Although listwise deletion is comparable across analyses, this method reduces statistical power (because it lowers the sample size, n). However, this method is unbiased as it is not a function of the outcome variable.[48]

Participants who did not experience any of these symptoms, namely, leg swelling, foot stiffness, skin discolouration, sensation, abnormal gait, disturbed sleep, leg heaviness, constipation or hard stools, were eliminated from the respective analyses. Only males were included in the early morning erection analysis. All eliminated participants were not included in the respective analyses as their data was deemed unavailable and they were coded as 'Missing data'.

Data analysis of participant interviews, investigator assessments and observations were carried out, and compared with subsequent assessment and observation data in order to observe changes.

Results

Participants

Of the 300 consecutive patients who attended WCUHKL from March until June 2016, 120 patients were found to be potentially eligible to participate in the study (Fig 1). There were 20 patients who were found to be ineligible after being interviewed (Fig 1). Reasons for this nonparticipation were: the patient was already using another microcurrent device (n=4), the patient was unable to comply with weekly visits to clinic (n=8), the patient had recently underwent metatarsal ray amputation (n=2), the patient was unable to give feedback (n=3), and the patient was unable to perform microcurrent treatment at home on a daily basis (n=3). The targeted 100 participants who met the inclusion criteria, were recruited after six weeks. The delay in recruitment was due to the limited availability of home microcurrent devices, resulting in some participants having to wait to start their microcurrent therapy. All 100 participants enrolled in this consecutive case series completed the four weeks of therapy. No adverse events were reported.

Demographics

A summary of demographic data of the 100 participants is presented in Table 1. Participants' mean age was 57.4 years (range: 31–86 years). The number of male participants (n=66) was almost double the number of female participants (n=34). Most of the wounds were in the extremities with DFU the largest category (n=64). Wound duration was >12 months in 73 participants. Of the 33 participants who displayed multiple wounds, nine had bilateral wounds, in these cases, analysis was performed on the ulcer with either the longest duration or the biggest size, ensuring that the number of treated ulcers was equal to the number of participants. Other types of wounds included: Ulcer (n=3), callus (n=1), necrotic tissue (n=1), traumatic ulcer from motor vehicle accident (n=1), post-total knee replacement surgical wound (n=1). Further details of three cases with different aetiologies are summarised below (Fig 2–4).

Table 1. Summary of patient demographics

Demographics		Frequency	Percentage (%)
Number of patients	Total, n	100	100
Gender	Male	66	66
	Female	34	34
Ethnicity	Malay	40	40
	Chinese	17	17
	Indian	43	43
Age group	≤49 years	18	18
	50–59 years	38	38
	60–69 years	38	38
	≥70 years	6	6
Wound aetiology	Diabetic foot ulcer	64	64
	Venous leg ulcer	24	24
	Pressure ulcer	5	5
	Others	7	7
Duration of wound	<6 months	15	15
	6–12 months	12	12
	>12 months	73	73

Fig 2. Case 1, 66-year-old male with a venous leg ulcer on left lower limb for more than five years' duration (11x6.9cm) (**a**). After four weeks' microcurrent treatment the wound had healed with full re-epithelialisation (**b**)

Case 1

A 66-year-old Chinese male presented with a VLU on left lower limb of more than five years' duration, and previously treated with standard wound care. Wound size before treatment was 11x6.9cm. The patient experienced leg stiffness and swelling, impacting on gait. After four weeks of microcurrent treatment (Fig 2b), the wound healed with full re-epithelialisation. Reported leg pain reduced by 80%. Leg stiffness and swelling reduced with improvement in gait. Requirement for tramadol 50mg/bd was reduced to nil. Improvement in leg colour as well as in early morning erection and frequency of bowel movement were reported.

Case 2

A 58-year-old Indian male presented with a category II sacral PU of more than five months' duration,

Fig 3. Case 2, 58 year-old Indian male with a category II sacral pressure ulcer of more than five months' duration (wound size 13.5x8.2x1cm) (**a**). After four weeks' microcurrent treatment the wound had reduced to (5.5x2.5cm) with 88% re-epithelialisation (**b**)

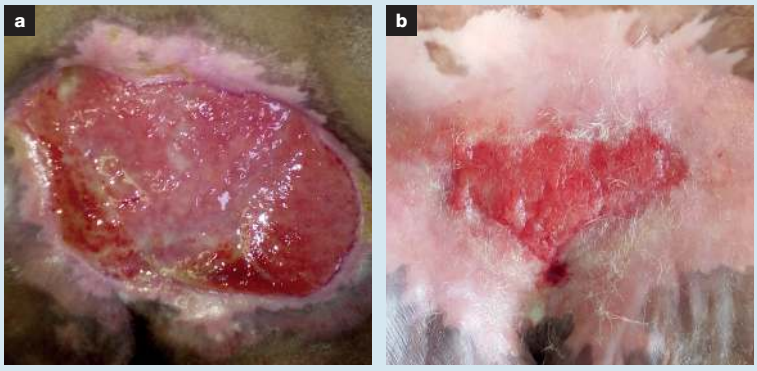


Fig 4. Case 3, 66 year-old Malay male with a right diabetic foot ulcer with ray's amputation carried out in 2015 (wound size 2x2x1.5cm) (**a**). After four weeks' microcurrent treatment the wound had completely healed (**b**)

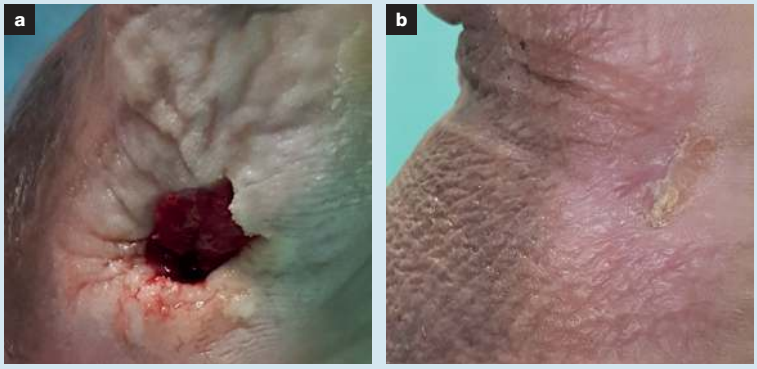


Table 2. Pair-wise comparisons between pre- and post-microcurrent therapy

Variable	Wound area	Pain score
Pre-treatment size mean±SD	39.1±68.10cm^2	6.0±1.75
Post-treatment size mean±SD	15.8±37.84cm^2	2.2±1.47
Mean of score difference (95% CI)	23.3 (15.8 to 30.8)	3.7 (3.35 to 4.09)
t-statistic (df)	6.1 (99)*	19.9 (89)*
p-value	<0.001	<0.001

SD—standard deviation; CI—confidence interval; df—degrees of freedom; *paired t-test

previously treated with standard wound care. Wound size before treatment was 13.5x8.2x1cm (Fig 3a). The patient reported leg pain and stiffness, impacting on gait. After four weeks of microcurrent treatment (Fig 3b), the wound size had reduced to 5.5x2.5cm, and had 88% re-epithelialisation. There was a 67% reduction in reported leg pain. There was a reduction in leg stiffness with improvement in gait. In addition, improvement in the quality of sleep.

Case 3

A 66-year-old Malay male presented with a right DFU with ray's amputation carried out in 2015, and treated with standard wound care. Wound size was 2x2x1.5cm (Fig 4a). The patient had foot stiffness, ankle swelling and numbness, and was treated with tramadol 50mg/bd to help with pain management. After four weeks of microcurrent treatment (Fig 4b), there was 100% re-epithelialisation and the wound had completely healed. Neuropathy pain reduced by 83% resulting in reduction of tramadol 50mg/bd to nil and improved sleep. The patient's gait improved due to a reduction in foot stiffness, numbness and ankle swelling. Foot colour and sensation improved. The patient experienced improvement in early morning erection and frequency of bowel movement.

Outcome data: primary endpoints

All 100 participants showed a reduction in wound size. Statistically significant reduction was reported in mean wound area over the four-week period, as shown in Table 2. Post-microcurrent treatment mean wound area of 15.8±37.84cm^2 was significantly ($p<0.001$) lower than pre-microcurrent treatment mean wound area of 39.1±68.10cm^2 (95% CI: 15.8cm^2 to 30.8cm^2). As illustrated in Fig 5, 16 participants had 100% wound area reduction or complete wound closure. Wounds were considered healed when completely covered with epithelium. A reduction of ≥50% wound area reduction was recorded in 70 patients (Fig 5).

With regards to pain levels, 89 participants complained of pain associated with their wound during the baseline evaluation, and 11 participants recorded no pain at baseline (VAS=0). Statistically significant reduction was reported in mean pain score in all 89 participants as shown in Table 2. Post-microcurrent treatment mean pain score of 2.2±1.47 was significantly ($p<0.001$) lower than pre-microcurrent treatment mean pain score of 6.0±1.75 (95% CI: 3.35 to 4.09). At the end of the study period, 11 participants were pain-free, and 59% of participants experienced ≥50% reduction in pain. Pain scores are recorded graphically in Fig 6.

Outcome data: secondary endpoints

The symptomatic scores and analysis in the secondary variances at the end of the four-week period are shown in Fig 7. Improvements were observed in patients reporting the following parameters: leg swelling, n=79 (100%); foot stiffness, n=97 (100%); skin discolouration, n=86 (93.5%); sensation, n=80 (98.8%); gait, n=89 (98.9%). Improved sleep quality was noted in 89 (94.7%) participants, and 95 (99%) participants commented on lightness in leg, 92 (100%) participants experienced improvement in frequency of bowel movement, and 46 (74.2%) male participants felt better early morning erection.

Although measurement of the frequency of tramadol intake was not a part of the design for this case series, this parameter was included in the Results and

Discussion section as participants who were prescribed tramadol as an analgesic medication observed changes in their frequency of intake once microcurrent treatment had started. Of the 46 participants prescribed tramadol, 38 stopped taking the painkiller at the end of the four-week period, five patients reduced their intake to once a day, and two only took it on an 'as needed' basis. This parameter was not analysed statistically. There was no change in tramadol intake for one patient although he did experience a 43% reduction in pain, and a 64% wound area reduction, as well as improvement in all parameters.

Discussion

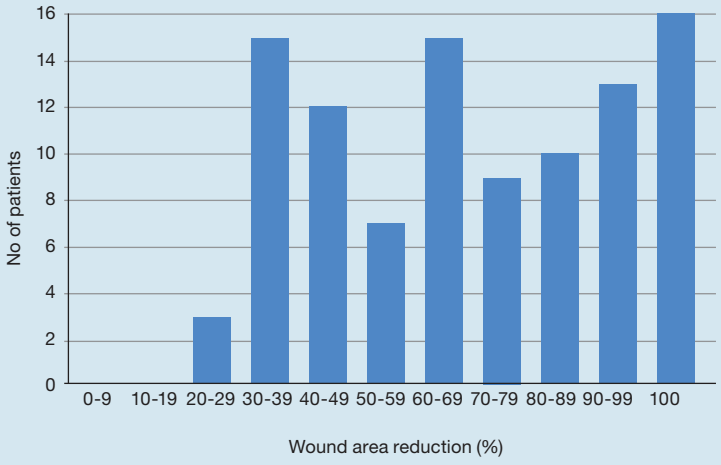
This consecutive case series analysis looked at microcurrent as an adjunct therapy to accelerate healing in wounds which were chronic or hard-to-heal. This was proven to be effective, and statistically significant, in terms of wound area ($p<0.001$) and pain score ($p<0.001$) reduction. Reduction in pain resulted in improved sleep quality. Patients had a likely increase in perfusion as well as improved skin colouration, early morning erection and sensation due to the effect of vasodilation of the vessels. There was also reduction in inflammatory symptoms such as leg swelling and foot stiffness. Patients reported their leg felt 'lighter' resulting in improvement of their gait. Improvement in frequency of bowel movement was also noted.

Published studies by Cheng et al.[49] states that microcurrent in the range of 10–1000µA stimulates cellular activity and regeneration by increasing the production of adenosine triphosphate (ATP), the energy that fuels all biochemical functions in the body, by an estimated 500%; protein synthesis necessary for tissue repair by 70%, and cell transport by 40%. A current higher than 1000µA decreased the results.[49] Galvanotaxis, which is the directed movement of cells within an electric field, is also observed in leukocytes and macrophages, which are key mediators in different stages of healing[50] as well as keratinocytes, vascular endothelial cells, osteoblasts, osteoclasts, chondrocytes and fibroblasts, which are cells responsible for tissue formation[51,52] This results in a decrease in inflammation and an increase in blood flow, which translates into the mode of action for wound healing.

Although the inflammatory phase is crucial in wound healing, prolonged or chronic inflammation—triggered when the mechanisms of acute inflammation fail to arrest infection or heal an injury—generates a series of destructive reactions that damage cells and lead to the clinical symptoms of disease. Ultimately, chronic inflammation is a failure of the body's immune system to maintain a healthy homeostatic state.[53,54] According to Senel et al., antioxidants play a major role in healing ischaemic skin wounds while oxygen free radicals play a major role in delaying healing of ischaemic wounds.[55]

When tissue becomes saturated by microcurrents, impedance increases due to maximised cellular redox potential and effective cellular-signaling stimuli.

Fig 5. Effect of microcurrent therapy on wound area



Redox potential, which is a representation of electron activity within cells and tissues, is useful for energetic evaluation of cellular metabolism.[56] When a tissue is depleted of electrons, the amount of oxygen free radicals increases causing metabolic function to degenerate and oxidative stress to increase. This increase in oxidative stress is known to inactivate metabolic enzymes, damage important cellular components, oxidise nucleic acids and lead to delayed wound healing, diabetes mellitus and hypertension, among others.[57] As free radicals are continuously generated in patients with chronic wounds or comorbidities, antioxidants in the form of electrons from induced microcurrent, move across the inflammatory barricades and into pockets of inflammation. These electrons are used to defend against the harmful effects of oxygen free radicals by neutralising the free radicals and therefore, enhancing normal function of beta-cells and vascular tissue.[58]

Fig 6. Effect of microcurrent therapy on pain reduction

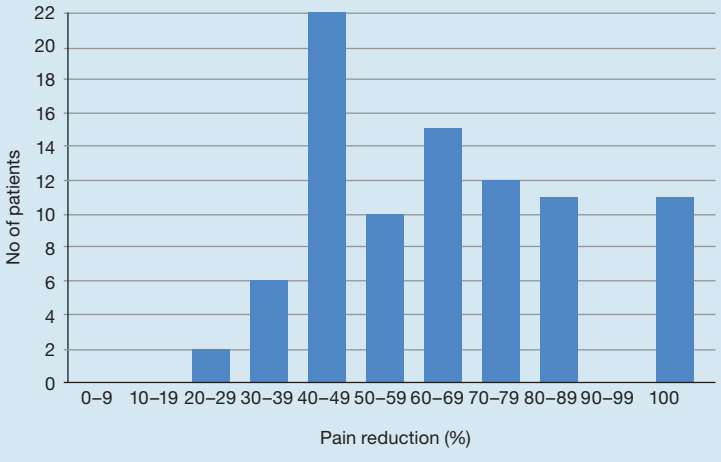
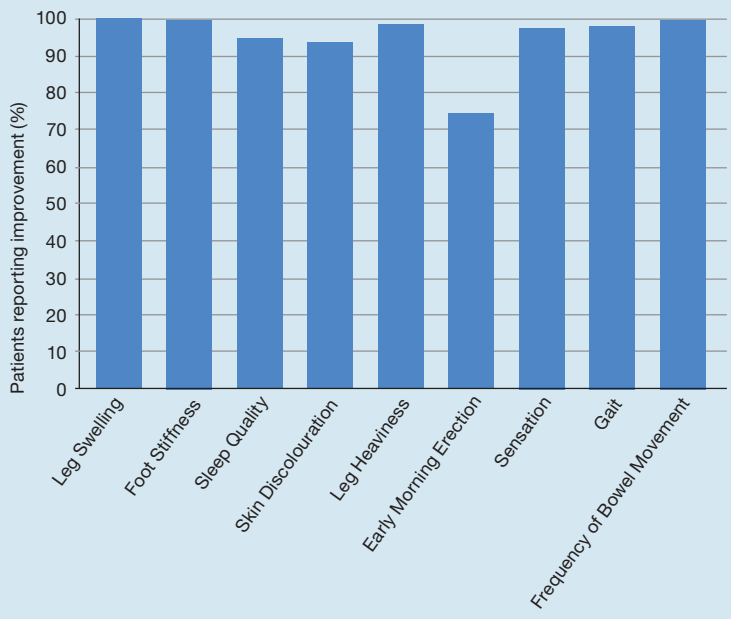


Fig 7. Effect of microcurrent therapy on various parameters



Pain is a huge factor in wound healing and it is possible that patients who suffer from acute and chronic wounds can interpret wound pain as a stressor. It is known that pain can contribute to stress and other psychological disorders.[59] It has been suggested that anxiety leading to stress can decrease one's pain threshold, reduce pain tolerance and impact the immune system. As a consequence of this, wound healing can be delayed.[59–61] In the field of wound care, pain can result from the wound itself and can also be caused by some wound treatments. Microcurrent has been proven to reduce TNF-α levels in terms of pain management.[62]

Hard-to-heal wounds, like DFU, fester because of insufficient blood supply at the wound site. However, application of microcurrent therapy can promote the growth of blood vessels by manipulating the body's naturally occurring electricity to form new vessels and increase blood supply to the wound.[63] Research has found that exogenous electrical stimulus can increase the growth of blood vessel networks by as much as 50%, activating the pathway for angiogenesis and enhancing vascular network growth.[63] Exogenous electrical stimulations are able to change the ionic environment surrounding the endothelial cells, which form the lining of blood vessels inside the cells. This stimulus can create links with proteins (proteins have existing charges that react with the applied electrical field) to activate pathway signals leading to the growth in the capillary network. Electrical stimulation also causes cells to produce chemicals called 'growth factors' that help sustain growing vascular networks.[63] Microcurrent has also been proven to increase nitric oxide, a potent vasodilator which increases perfusion to the wound.[64] As a result, wound closure would be enhanced, leading to faster healing[65–67] by stimulating tissue healing. This results in cell migration, proliferation and synthesis of new tissue which are essential in the healing process.[68] By imitating endogenous electrical signals that guide cellular behaviour, microcurrent may be a therapeutic alternative where natural healing has failed.

It can be postulated that microcurrent's role in reducing inflammation and improving perfusion accelerates wound healing and improves HRQoL. Findings from other studies state that limited mobility can lead to periods of inactivity and social isolation which is a source of frustration to patients with leg ulcer pain.[69] A high level of mobility was evident during participant interviews as inflammation symptoms, such as leg swelling and foot stiffness reduced. Improved gait in participants due to reduction in leg heaviness was also observed during treatment. Almost all the participants noticed an improvement in their walk; they had been attempting to limit the pain originating from their wound and this had affected their mobility and confidence. Reduced pain resulted not only in a reduced intake of tramadol for some participants, but had also led to improved sleep quality and improved energy levels. Participants were reluctant to take oral analgaesia if not needed as they were apprehensive about possible side effects and dependency on the painkiller. Previously, due to disturbed sleep, these participants had to rest in the day and limit their daily activity levels.

Increased perfusion due to vasodilation not only improved sensation and early morning erection, but also improved skin colouration. Poor bowel movement can be due to physiological stress or damage to the digestive tract nerves.[70,71] Activating the pathway for angiogenesis and enhancing vascular network growth improved frequency of bowel movement.

Microcurrent therapy appears to be an ideal adjunctive therapy in wound healing as no related complications or adverse effects have been reported in the existing literature. Given the targeted, localised nature of such wound treatment, the application of microcurrent therapy could replace or reduce the need for drug-based treatments which affect the entire body and which may carry side effects. Moreover, the therapy is safe and easy to use.

Limitations

The limitation of a case series is the absence of a control group which accounts for observation bias. Due to this, it is classified as only a Level IV evidence by the Centre for Evidence-Based Medicine, Oxford.[72] As case series studies are susceptible to bias, a detailed method was followed during this study for the wound management and microcurrent procedures, data collection, analysis and documentation. Conducting a randomised

controlled trial (RCT) to further investigate the effects of this therapy is required.

Another limitation is that the rate of conversion from theory to practical application has been slow, although quite a number of developments in basic research of wound repair using microcurrent is present.[73] This is due to lack of an accurate wound model as most studies have been conducted on animals. Compared with humans, difference in dermis thickness, presence or absence of hair, and injury location in animals may affect electrical current flow.[74] Moreover, there are differences in the duration and dosing of electrical stimulation among microcurrent devices. The gold standard for assessing clinical efficacy of microcurrent in wound healing would be a human RCT.

Conclusion

The potential for microcurrent treatment of wounds is far reaching. The combination of standard wound care coupled with microcurrent as an adjunctive therapy was proven to be effective in significantly reducing wound size and pain levels in all participants. Microcurrent may help redress an underlying physiological dysfunction as well as reducing other symptoms; its mechanism of action appears to be a trigger or facilitator of the healing process, unlike some new approaches, such as exogenous growth factors, which have specific targets in the healing cascade.[10] No adverse effects of the microcurrent therapy were reported. The ease of use of microcurrent devices advocate its use in accelerating wound healing. It should be applied as an adjunctive wound care therapy. JWC

References

1 Franks PJ, Moffatt CJ. Quality of life issues in chronic wound management. Br J Community Nurs 1999; 4(6):283–289. https://doi.org/10.12968/bjcn.1999.4.6.7476

2 Mayer EA. The neurobiology of stress and gastrointestinal disease. Gut 2000; 47(6):861–869. https://doi.org/10.1136/gut.47.6.861

3 Soon SL, Chen SC. What are wound care outcomes? Wounds 2004; 16(5):150–156

4 Blome C, Baade K, Sebastian Debus E et al. The Wound-QoL: a short questionnaire measuring quality of life in patients with chronic wounds based on three established disease-specific instruments. Wound Repair Regen 2014; 22(4):504–514. https://doi.org/10.1111/wrr.12193

5 Faria E, Blanes L, Hochman B et al. Health-related quality of life, self-esteem, and functional status of patients with leg ulcers. Wounds. 2011; 23:1,4–10

6 To WT, Hart J, De Ridder D, Vanneste S. Considering the influence of stimulation parameters on the effect of conventional and high-definition transcranial direct current stimulation. Expert Rev Med Devices 2016; 13(4):391–404. https://doi.org/10.1586/17434440.2016.1153968

7 Franek A, Kostur R, Polak A et al. Using high-voltage electrical stimulation in the treatment of recalcitrant pressure ulcers: results of a randomized, controlled clinical study. Ostomy Wound Manage 2012; 58(3):30–44

8 Polak A, Franek A, Taradaj J. High voltage pulsed current electrical stimulation in wound treatment. Adv Wound Care 2014; 3(2):104–117. https://doi.org/10.1089/wound.2013.0445

9 Becker RO, Selden G. The body electric: electromagnetism and the foundation of life. Morrow 1985

10 Poltawski L, Watson T. Bioelectricity and microcurrent therapy for tissue healing: a narrative review. Physical Therapy Reviews 2009; 14(2):104–114. https://doi.org/10.1179/174328809X405973

11 Picker RI. Low-volt pulsed microamp stimulation: Part 1. Clin Manage 1989; 9:28–33

12 Ahmed A, Elgayed S, Ibrahim I. Polarity effect of microcurrent electrical stimulation on tendon healing: biomechanical and histopathological studies. J Adv Res 2012; 3(2):109 –117. https://doi.org/10.1016/j.jare.2011.05.004

13 McMakin CR, Oschman JL. Visceral and somatic disorders: tissue softening with frequency-specific microcurrent. J Altern Complement Med 2013; 19(2):170–177. https://doi.org/10.1089/acm.2012.0384

14 Barker AT, Jaffe LF, Vanable JW Jr. The glabrous epidermis of cavies contains a powerful battery. Am J Physiol 1982; 242(3):R358–R366

15 Wolcott LE, Wheeler PC, Hardwicke HM, Rowley BA. Accelerated healing of skin ulcer by electrotherapy: preliminary clinical results. South Med J 1969; 62(7):795–801. https://tinyurl.com/ybybcppe

16 Gault WR, Gatens PF Jr. Use of low intensity direct current in management of ischemic skin ulcers. Phys Ther 1976; 56(3):265–269. https://doi.org/10.1093/ptj/56.3.265

17 Carley PJ, Wainapel SF. Electrotherapy for acceleration of wound healing: low intensity direct current. Arch Phys Med Rehabil 1985; 66(7):443–446

18 Foulds IS, Barker AT. Human skin battery potentials and their possible role in wound healing. Br J Dermatol 1983; 109(5):515–522. https://doi.org/10.1111/j.1365-2133.1983.tb07673.x

19 Nuccitelli R. Endogenous ionic currents and DC electric fields in multicellular animal tissues. Bioelectromagnetics 1992; 13(S1 Suppl 1):147–157. https://doi.org/10.1002/bem.2250130714

20 Barker AT, Jaffe LF, Vanable JW Jr. The glabrous epidermis of cavies contains a powerful battery. Am J Physiol 1982; 242(3):R358–R366

21 Karba R, Šemrov D, Vodovnik L et al. DC electrical stimulation for chronic wound healing enhancement Part 1. Clinical study and determination of electrical field distribution in the numerical wound model. Bioelectrochem Bioenerg 1997; 43(2):265–270. https://doi.org/10.1016/S0302-4598(96)05192-6

22 Elamed. (2009). What is PEMF therapy? https://tinyurl.com/ycss3pg7. (accessed 13 April 2018)

23 Altered States. (1998). Enhance your life force with PEMF pulsed magnetic field therapy. https://tinyurl.com/y7p8jdlq (accessed 13 April 2018)

24 PEMF Therapy Education. (2016). How PEMF Therapy Improves Circulation. https://tinyurl.com/yapwhzuj (accessed 13 April 2018)

25 Ross CL, Harrison BS. The use of magnetic field for the reduction of inflammation: a review of the history and therapeutic results. Altern Ther Health Med 2013; 19(2):47–54

26 Broichsitter B, Lamia A, Geuna S et al. Does pulsed magnetic field therapy influence nerve regeneration in the median nerve model of the rat? Biomed Res Int 2014; 2014:401760. https://doi.org/10.1155/2014/401760

27 Shupak NM, McKay JC, Nielson WR et al. Exposure to a specific pulsed low-frequency magnetic field: a double-blind placebo-controlled study of effects on pain ratings in rheumatoid arthritis and fibromyalgia patients. 2006; 11(2):85-90

28 Strauch B, Patel MK, Navarro JA et al. Pulsed magnetic fields accelerate cutaneous wound healing in rats. Plast Reconstr Surg 2007; 120(2):425–430. https://doi.org/10.1097/01.prs.0000267700.15452.d0

29 Guerriero F, Botarelli E, Mele G et al. Effectiveness of an innovative pulsed electromagnetic fields stimulation in healing of untreatable skin ulcers in the frail elderly: two case reports. Case Rep Dermatol Med 2015;2015:576580. https://doi.org/10.1155/2015/576580

30 Kuliev RA, Babaev RF. [A magnetic field in the combined treatment of suppurative wounds in diabetes mellitus]. Vestn Khir Im I I Grek 1992; 148(1):33–36

31 The Joanna Briggs Institute. (2016). JBI critical appraisal checklist for case series. https://tinyurl.com/y8hwc7ym (accessed 16 April 2018)

32 Dekkers OM, Egger M, Altman DG, Vandenbroucke JP. Distinguishing case series from cohort studies. Ann Intern Med 2012; 156(1 Part 1): 37–40. https://doi.org/10.7326/0003-4819-156-1-201201030-00006

33 Cohen D, Crabtree B. Robert Wood Johnson Foundation (2006). Qualitative Research Guidelines Project. https://tinyurl.com/jlkppey (accessed 13 April 2018)

34 Flanagan M, Vogensen H, Haase L. World Wide Wounds. Case series investigating the experience of pain in patients with chronic venous leg ulcers treated with a foam dressing releasing ibuprofen. 2006. https://tinyurl.com/64kme8 (accessed 13 April 2018)

35 World Medical Association. WMA Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA 2013; 310(20): 2191-2194. https://doi.org/10.1001/jama.2013.281053

36 Avazzia, Inc. (2014) Technology. https://tinyurl.com/yd7s3zka (accessed 13 April 2018)

37 Carey TS, Boden SD. A critical guide to case series reports. Spine 2003; 28(15):1631–1634. https://doi.org/10.1097/01.BRS.0000083174.84050.E5

38 Mustoe TA, OShaughnessy K, Kloeters O. Chronic wound pathogenesis and current treatment strategies: a unifying hypothesis. Plast Reconstr Surg 2006; 117(7 Suppl):35S–41S. https://doi.org/10.1097/01.prs.0000225431.63010.1b

39 DrSircus. (2012). Pulsed electromagnetic field therapy for cancer and

Reflective questions

- How does adjunctive therapies like microcurrent help in alleviating pain in patients with chronic wounds?
- What role, if any, do adjunctive therapies play in wound healing?
- In what way, if at all, do adjunctive therapies have a role in the management of chronic complex wounds?

pain. https://tinyurl.com/yblsqw5s. (accessed 13 April 2018)
40 Truth in Aging. (2015). The truth about facial massage and lymphatic drainage. https://tinyurl.com/y75xmzpm (accessed 13 April 2018)
41 Singh J. Microcurrent electrical neuromuscular stimulation. In: Textbook of Electrotherapy (2nd Edn). Jaypee 2012
42 Wewers ME, Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. Res Nurs Health 1990;13(4):227–236. https://doi.org/10.1002/nur.4770130405
43 Ankle Injury Management. (2013). Guide for assessing ankle range of movement for the AIM trial. https://tinyurl.com/ycak9wsk (accessed 13 April 2018)
44 Delfini Evidence- and Value-based Solutions for Health Care (2003). Problems with case series. https://tinyurl.com/yb5q32jy (accessed 13 April 2018)
45 Yu TS, Tse LA. Clinical Epidemiology Workshop 3—Sources of bias in case series, patient cohorts, and randomised controlled trials. Hong Kong Med J 2011; 17(6):478–479
46 UCLA; Statistical Consulting Group. (2006). Missing data in SAS. https://tinyurl.com/ybwvlojp (accessed 13 April 2018)
47 Little R, Rubin D. Statistical Analysis with Missing Data (2nd edn). Wiley, Interscience, 2002
48 Humphries M. Missing data and how to deal: an overview of missing data. https://tinyurl.com/y6vdwqpu (accessed 13 April 2018)
49 Cheng N, Van Hoof H, Bockx E et al. The effects of electric currents on ATP generation, protein synthesis, and membrane transport of rat skin. Clin Orthop Relat Res 1982; (171):264–272
50 Wong ME, Hollinger JO, Pinero GJ. Integrated processes responsible for soft tissue healing. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996; 82(5):475–492. https://doi.org/10.1016/S1079-2104(96)80190-9
51 Zhao M, Agius-Fernandez A, Forrester JV, McCaig CD. Directed migration of corneal epithelial sheets in physiological electric fields. Invest Ophthalmol Vis Sci 1996; 37(13):2548–2558
52 Chao PH, Roy R, Mauck RL et al. Chondrocyte translocation response to direct current electric fields. J Biomech Eng 2000;122(3):261–267. https://doi.org/10.1115/1.429661
53 Calder PC, Albers R, Antoine JM et al. Inflammatory disease processes and interactions with nutrition. Br J Nutr 2009; 101(1 Suppl 1):S1–S45. https://doi.org/10.1017/S0007114508076228
54 Levine TB, Levine AB. Inflammation. In: Metabolic syndrome and cardiovascular disease 2nd ed. Blackwell Publishing.2012.
55 Senel O, Cetinkale O, Özbay G et al. Oxygen free radicals impair wound healing in ischemic rat skin. Ann Plast Surg 1997; 39(5):516–523. https://doi.org/10.1097/00000637-199711000-00012
56 Clark WM. Oxidation-Reduction Potentials of Organic Systems, Williams & Wilkins Company, 1960
57 Rahman T, Hosen I, Islam MM, Shekhar HU. Oxidative stress and human health. Advances in bioscience and biotechnology 2012; 03(07 7A):997–1019. https://doi.org/10.4236/abb.2012.327123
58 Lee BY, Al-Waili N, Stubbs D et al. Ultra-low microcurrent in the management of diabetes mellitus, hypertension and chronic wounds: report of twelve cases and discussion of mechanism of action. Int J Med Sci 2009; 7(1):29–35
59 Upton D, Solowiej K. Pain and stress as contributors to delayed wound healing. Wound Practice & Research. 2010; 18(3):114–122
60 Melzack N. Pain and stress: a new perspective. In Psychosocial factors in Pain. Guilford Press, 1999
61 Gouin JP, Kiecolt-Glaser JK. The impact of psychological stress on wound healing: methods and mechanisms. Immunol Allergy Clin North Am 2011; 31(1):81–93. https://doi.org/10.1016/j.iac.2010.09.010
62 McMakin CR, Gregory WM, Phillips TM. Cytokine changes with microcurrent treatment of fibromyalgia associated with cervical spine trauma. J Bodyw Mov Ther 2005; 9(3):169–176. https://doi.org/10.1016/j.jbmt.2004.12.003
63 Medical Xpress. (2014) Study tests range of electrical frequencies that help heal chronic wounds. https://tinyurl.com/ybvjtjqs (accessed 13 April 2018)
64 Gabriel A, Sobota R, Gialich S, Maxwell GP. The use of targeted microcurrent therapy in postoperative pain management. Plast Surg Nurs 2013; 33(1):6–8. https://doi.org/10.1097/PSN.0b013e3182844219
65 Isenberg JS, Ridnour LA, Espey MG et al. Nitric oxide in wound-healing. Microsurgery 2005; 25(5):442–451. https://doi.org/10.1002/micr.20168
66 Rizk M, Witte MB, Barbul A. Nitric oxide and wound healing. World J Surg 2004; 28(3):301–306. https://doi.org/10.1007/s00268-003-7396-7
67 Witte MB, Barbul A. Role of nitric oxide in wound repair. Am J Surg 2002; 183(4):406–412. https://doi.org/10.1016/S0002-9610(02)00815-2
68 Wong ME, Hollinger JO, Pinero GJ. Integrated processes responsible for soft tissue healing. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996; 82(5):475–492. https://doi.org/10.1016/S1079-2104(96)80190-9
69 Phillips T, Stanton B, Provan A, Lew R. A study of the impact of leg ulcers on quality of life: financial, social, and psychologic implications. J Am Acad Dermatol 1994; 31(1):49–53. https://doi.org/10.1016/S0190-9622(94)70134-2
70 Lins Neto MÁ, Moreno KA, da Graça RC, Lima SM. Constipation prevalence in diabetic patients. Journal of Coloproctology 2014; 34(2):83–86. https://doi.org/10.1016/j.jcol.2014.04.001
71 Anna Schaefer. Healthline (2015). Diabetes and constipation: what's the connection? https://tinyurl.com/yatekhub (accessed 13 April 2018)
72 CEBM. (2009). Oxford Centre for Evidence-based Medicine – Levels of evidence. https://tinyurl.com/ochdj3q (accessed 13 April 2018)
73 Yu C. Zong-Qian H, Peng R-Y. Effects and mechanisms of a microcurrent dressing on skin wound healing: a review. Military Medical Research 2014; 1(24). https://doi.org/10.1186/2054-9369-1-24
74 Ojingwa JC, Isseroff RR. Electrical stimulation of wound healing. J Invest Dermatol 2003; 121(1):1–12. https://doi.org/10.1046/j.1523-1747.2003.12454.x