Residual wounds rarely heal spontaneously and are prone to reoccur, especially severe burns. Many forms of wound treatment have been applied to residual burn lesions including surgical, chemical, enzymatic, mechanical, and biological techniques. Experimental therapeutic ultrasound (at lower frequencies) as a means of wound treatment has seen promising results in hastening wound healing. Studies of ultrasound treatment in patients with venous ulcers showed a significant difference in healing with a nearly 40% improvement compared to a control.

A Pilot Study of Ultrasonically-assisted Treatment of Residual Burn Wounds

Xiaolu Li, MD, PhD; Shunli Liu; Xinan Lai, PhD; Gaoxing Luo, MD, PhD; Hong Yan, MD, PhD; Xianhui Huang; Yuesheng Huang, MD, PhD; Yizhi Peng, MD, PhD

Abstract: Objective. To evaluate the use of a noninvasive, low-frequency ultrasound device to treat residual burn wounds as an adjunct to regular wound dressing therapy. Methods. Nineteen patients with 38 residual wounds (served as self control) with an average post-burn duration of 94.6 days were recruited. Low-frequency ultrasound at 40 kHz was delivered in the ultrasonic group by a handheld probe, using normal saline as the irrigation medium. The control group had dressings changed with saline used as the coupling medium. Each wound was treated for 2 weeks (a total of 7 treatments; once every 2 days). Bacterial colony counts were done before the first and then after the fourth treatment. Serial color photographs were taken to evaluate the wound response at each visit. Healing time and percentage closure were determined. Results. Symptomatic relief (pain and odor reduction) was achieved in all patients. The healing percentage for the wounds treated with ultrasound was 100%. The healing rate in the treatment group was 84%, while the healing rate was 71.46% ± 31.06%; both were significantly higher compared to the control wounds (P < 0.01). The bacterial clearance rate in the ultrasound group (82.85 ± 19.13) increased significantly compared to the control group (35.55 ± 16.99). There were no major complications with the treatment, which was relatively painless. Conclusion. The application of low-frequency ultrasound treatment may heal residual burn wounds when a nonsurgical dressing change protocol has failed. The significant decrease in wound bioburden was definitely related to the use of the ultrasound treatment. No adverse reactions to the ultrasound treatment were found during the study.
The aim of this prospective pilot study was to evaluate the tolerability and effectiveness of low-frequency ultrasound in healing residual burn wounds as an adjunct to traditional wound dressing therapy.

Methods

Patient selection. Residual burn wounds were defined as unhealed wounds 3 weeks after injury. Patients admitted to the Burn Unit (Southwest Hospital, Chongqing, China) between 18- and 60-years-old, both male and female, with no serious complications of the heart, liver, kidney, or blood system, and no serious systemic infection were recruited. Patients with diabetic ulcers were required to control their blood sugar levels at ≤10 mmol/L and to maintain this level for more than 2 weeks with no acute metabolic disorders. The Southwest Hospital Ethics Committee approved the study protocol. All patients willingly participated in the trial and gave informed consent.

Nineteen patients who had residual burn wounds at least 2 months post injury were enrolled in the study. One patient was dropped from the study due to noncompliance with the protocol. All patients had more than two residual wounds on their trunk or extremities. Two lesions, located in a similar body part, from each patient were recruited: one wound was treated with ultrasound (treatment group), the other was treated with traditional wound dressings (control group). One patient had diabetes, three had hypertension, and two had contaminated wounds. The other 13 patients did not have any diseases. Sixteen cases had wounds on the extremities; the remaining three cases had wounds located on the trunk. Standard wound assessment forms were completed for each patient during enrollment.

Exclusion criteria. Patients who were younger than 18 years or older than 60 years; those who had difficult healing wounds related to malignant disease; those who had a serious disease of the heart or liver; or had a blood producing disorder; inclination to uncontrolled vessel thrombosis, uncontrolled high blood sugar level, shock, serious systemic infection, and pregnant or breastfeeding women. Patients with residual defects on the head or face were also excluded from the study.

Patient removal or dropout. Patients who could not continue with the treatment and had to withdrawal from the study (various reasons); those who could not finish all the test items (various reasons); those who encountered unexpected events during the treatment and had to stop medication; those who annulled their agreement acknowledging their awareness of the conditions; and those who had serious complications/infections were removed from the trial.

Experimental methods. The initial wound size (cm²) was calculated by multiplying the maximum length and width of the wound, which was measured at each visit. The wound was categorized as “healed” when the skin healed completely. One certified clinician completed the respective therapies once every 2 days. All dressings were left undisturbed until the next scheduled treatment. Serial color digital photos of the wounds were taken at the end of every treatment to evaluate the response following each visit. Standard questionnaires were completed during the treatment and any symptoms or side effects were also recorded. All patients were followed up for a minimum of 4 weeks.

Ultrasound therapy. The Haiwei180 ultrasound (Chuanyi Company, Sichuan, China) is a compact unit that produces a low 25-kHz frequency through a handheld probe. No thermal energy is generated; hence, no cooling system is required. During the treatment, isotonic normal saline was used as an irrigation medium between the handheld probe and the wound. The ultrasonic amplitude was set at maximum and the treatment was applied for 10 seconds per probe head area (1 cm x 1 cm) onto the edge and surface of all wounds. Each patient underwent 7 treatments at an interval of 2 days.

Traditional therapy. The wounds were washed with 500-mL of isotonic normal saline at each treatment. All the wounds in both groups were semi-exposed with one sheet of povidone iodine gauze used as a cover until the next treatment.

Observation and determination of indices. The wounds were observed dynamically in the process of medication. Wound secretion and other conditions (odor, swelling, pain, etc.) were recorded every 2 days—assessment after each treatment session was also recorded.

Wound healing time and percentage. A series of digital photographs of each wound, before and after each treatment, were taken with a ruler laid next to the wound. The length and width of the wound was recorded to calculate wound area. Wound healing percentage and time elapsed since the last treatment (treatment was finished if the wound healed completely during the study period).

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\text{wound healing percentage} = \frac{\text{wound area post last treatment}}{(\text{baseline wound area}) \times 100}\]

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\text{wound area} = \text{wound area baseline} - \text{wound area post last treatment}
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Bacterial clearance rate. Wound swab cultures were collected at baseline (prior to initial application of either the ultrasound or control wound dressing change at the initial visit) and after the fourth visit, respectively. All cultures were collected as follows: 1) A rayon-tipped swab applicator was rotated in a zig-zag pattern on the wound surface; 2) the tip of the swab was then inserted into a sterile round bottom polypropylene tube containing a non-nutritive, highly conductive transport medium; 3) all culture samples were sent immediately to the laboratory for bacterial colony count analysis. Then the log colony forming unit counts (CFU/mL), based on wound area (cm²), was calculated as CFU/mL/cm². The wound bacterial clearance rate was calculated as follows:

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\text{wound bacterial clearance rate (\%)} = \frac{\text{baseline CFU/mL/cm}^2 - \text{the fourth CFU/mL/cm}^2}{(\text{baseline CFU/mL/cm}^2) \times 100}
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Safety assessment. Systemic reaction, side effects, abnormal indices, and skin irritation were assessed and determined according to the 5 levels: clearly relevant, probably relevant, probably irrelevant, clearly irrelevant, and unable to determine. The degree and incidence of side effects were described.

Statistical Analysis
Chi-squared analysis was used to compare the ordinal and categorical data, and the t-test was used to compare the average of continuous data. Statistical software (SPSS) was used to analyze data.

Results
Nineteen eligible patients (2 women, 17 men) were carefully observed. All patients served as self-control. The patients ranged in age 30 to 56 years (average age 44.9). The burn wounds had existed from 71 days to 256 days after injury. The average wound duration was 94.6 days after injury.

Residual wound healing rate. The total healing rate of the residual wounds in the treatment group was significantly greater than that in the control group, on average 2.38 times greater \((P < 0.01)\). This was especially obvious in the mild and moderate infectious subgroups when the study ended (Table 1).

Treatment efficacy rate. Comprehensive efficacy improved significantly in the treatment group compared to that of the control group. A statistically significant difference was found in the “obviously effective” rate
between the two groups ($t = 2.52, P < 0.05$; Figure 1).

**Bacterial clearance rate.** The log count (CFU/mL) for any microbe present at baseline and the fourth treatment were compared to determine if the ultrasound treatment affected colony counts. Overall, the results demonstrated a greater reduction in log colony counts for the treatment group wounds ($P < 0.01$; Table 1).

**Safety assessment.**
No significant differences between the two groups were found in routine blood, liver, and renal function tests. No local allergic or systemic symptoms were found. Side effects were not found with the use of the ultrasound treatment in any of the 19 patients.

**Case Briefs**

**Case 1:** A 36-year-old woman with a residual burn wound on the left chest area 123 days after flame injury. The original area of the wound was 38 cm$^2$ and the bacterial colony count was 10,000 CFU/mL at baseline. After 4 ultrasound treatments, the bacterial colony count was zero. Two weeks later the wound measured 2 cm$^2$ (Figures 2, 3).

**Case 2:** A 37-year-old man with a residual burn wound on the left ankle 2 years after injury. The baseline area of the wound was 1.34 cm$^2$. The wound had pus, slough, and was both reddish and odorous. The bacterial count was $6.7 \times 10^5$/CFU/mL/cm$^2$ before the treatment. The count decreased to $2.47 \times 10^2$/CFU/mL/cm$^2$ after 4 ultrasonic therapy treatments. Two weeks later, 0.2 cm$^2$ remained unhealed (Figures 4, 5).

**Discussion**
Residual burn wounds are common, usually festered, and infected blisters often reoccur during the long healing process associated with deep burn wounds. There are two main causes for the formation of residual wounds: 1) blocking of the sebaceous and sweat glands that remain inside the dermis, which induce consequent infections during wound healing in deep, second degree burns; 2) newly grown skin is too thin to bear pressure and is prone to repeated infections. Therefore, the ideal nonoperative method for treating residual burn wounds is to control infection, improve circulation, and regenerate cells. The topical instrument dealing with residual wounds should reduce slough and bacteria and increase circulation to the wound.

It has been more than 70 years since ultrasound was first utilized as therapy for soft tissue injuries. Ultrasound has since been used to treat a wide variety of
disorders. Therapeutic ultrasound has been recognized as one of several treatment methods used to enhance healing of pressure ulcers, in addition to wound cleansing, sharp debridement, wound dressings, and electrical stimulation. Low-intensity ultrasound produces two effects—stable cavitation and acoustic streaming. These effects change cell membrane permeability and increases cellular metabolite diffusion. The mechanical energy of ultrasound has been applied to debride and cleanse wounds. Additionally, other ultrasound effects including promotion of histamine release, mast cell degranulation, angiogenesis, increases in intracellular calcium, increases in collagen deposition and wound-breaking (or tensile) strength, and wound size reduction have been demonstrated.

This pilot study intended to assess the acceptability and tolerability of a novel form of ultrasonic treatment (UWI-Haiwei ultrasonic debridement machine) on patients whose sloughy, fibrotic, residual burn wounds had failed to respond to traditional treatment regimens. The ultrasound frequency (40 kHz) was used in the present study based on its efficient use in experiments on rats. The ultrasound frequency and length of the therapeutic sessions were varied and dependent on the severity of infection and size of the individual wound. Each patient served as his or her own control. This study demonstrated that residual wounds of the treatment group improved dramatically within 2 weeks, and that the healing rate was significantly higher than that of the control group. An interesting observation from the study was that improvement in healing continued after the treatment and that complete healing might be gained by continuing treatment.

Some studies doubt that the mechanical force applied to the wounds may “drive” the microbes deeper into the tissue creating a wound with bacterial colonization into one with a spreading infection—this particular phenomenon was not observed in the present study. Conversely, all wounds treated with ultrasound reduced odor and local signs of cellulitis. The bacterial colony counts in the treatment group decreased significantly after 3 treatments with the ultrasonic debridement machine, whereas the control group showed a small difference of the bioburden between the baseline and the fourth treatment. The clearance of the bacteria of ultrasonic wounds was significantly higher than that of the control wounds.

No definite systemic or local side effects were observed in this study.

Conclusion
This study shows that treatment with an ultrasonic debridement machine effectively improves the healing process of residual burn wounds, restrains the growth of bacteria in wounds, which may reduce the frequency of dressing changes, and does not cause much pain.

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