**PICO Question:** In hospitalized patients with Stage III and IV pressure ulcers, does pulsatile lavage provide more effective debridement than non-contact low-frequency ultrasound therapy as measured by healing time or wound size reduction?

**Introduction**

Pressure ulcers are a serious complicating factor to hospital stay and wheelchair use; ulcers have major impacts on quality of life, financial burden, and mortality. The National Pressure Ulcer Advisory Panel defines a pressure ulcer as a localized injury to the skin and/or underlying soft tissue that is typically over a bony prominence as a result of pressure, or pressure in combination with shear or friction.1 A pressure ulcer can be categorized into 1 of 6 stages: I, II, III, IV, Suspected Deep Tissue Injury, and Unstageable.1 Ulcers are staged based on thickness of tissue loss. Pressure ulcers are difficult to heal and may persist for months to years.1

The prevalence of pressure ulcers in hospital settings is increasing at an alarming rate. In 2004, the reported national rates of pressure ulcer prevalence was 14-17%.2,3 Likewise, the results of a study conducted in 2009 also determined a 15.8% prevalence rate.4 The average cost of pressure ulcer care per patient is estimated at $43,180 per hospital stay.5,6 Furthermore, the annual cost of treating hospital-acquired pressure ulcer ulcers is estimated at $11 billion.7-10 Recent studies indicate a death rate of approximately 1 in 25 in hospitalizations relating to pressure ulcer as a primary diagnosis, and 1 in 8 relating to pressure ulcer as a secondary diagnosis.5,6 Pressure ulcers increase length of stay and require off-loading positioning that can lead to deconditioning, atrophy, decreased socialization, interruptions in bowel function, and lung complications.

A myriad of treatment options are available for management of pressure ulcers, including but not limited to: pulsed radio frequency energy therapy, hyperbaric oxygen, electrotherapy or shock wave therapy, therapeutic ultrasound, hydrotherapyincluding whirlpool and pulsatile lavage, electromagnetic therapy, non-contact low-frequency ultrasound therapy, laser therapy, negative pressure therapy, enzymatic debridement, electrostimulation, and vasopneumatic devices. Currently, no standard of care exists to delineate an optimal adjuvant therapy modality based on wound characteristics. A therapeutic approach that is uniformly effective, safe, well tolerated, noninvasive, and easy to apply remains elusive because wound presentation varies and patient response varies.1 Clinicians must choose their intervention method based on what equipment they have available, evidence from research, and past experience.

Two treatment modalities are commonly utilized in acute care settings that can be administered bedside: pulsatile lavage (PL) and non-contact low-frequency ultrasound (NCLFU). These treatments can be applied by physical therapists and may enable patients to avoid surgical irrigation and debridement. This eliminates the use of anesthesia, which is especially beneficial for patients in critical condition, and is also more cost-effective.11

Pulsatile lavage is the delivery of an irrigating solution under pressure that is produced by an electrically powered device; the solution is concurrently removed via suction.12 PL effects wound healing in several ways. The continuous suction evacuates the saline fluid, exudates, and debris from the wound bed. This prevents its reaccumulation on the wound and resultant reinfection. Secondly, by maintaining circumferential contact of the nozzle on the wound surface, this causes a negative pressure-like effect on that area of the wound causing cell strain and microdeformation, in addition to the shear stress of the saline fluid on the cell at the output pressure of the device. Numerous studies have shown that this mechanical stress and strain brings about the tissue growth response and helps in early formation of healthy granulation tissue. PL also induces negative pressure which enhances blood flow.13

In comparison, non-contact low-frequency ultrasound therapy expedites wound healing in different ways. This handheld device works at a frequency of 25 kHz and an intensity of 35-40 W/cm2 coupled with an irrigation liquid that flows through the probe.14 The acoustical cavitation15 of NCLFU has been proven in human, plant, and animal in vitro studies16. The cavitation creates and oscillates microscopic bubbles, i.e. vapor-filled voids. When these voids reach a size that resonates with the frequency of the sound field, they act as powerful concentrators of acoustic energy into shearing and microstreaming fields. The movement and compression of these voids can alter cellular activities within the tissues subjected to the ultrasound energy.17 Microstreaming occurs when ultrasound’s sound waves produce physical forces capable of displacing ions and small molecules.18 Although some organelles and molecules are incapable of movement, others are free floating and may be driven to move around these stationary structures.19 This mechanical pressure produces a unidirectional movement of fluid along and around cell membranes. The alteration of cell membrane activity, and therefore cellular activity, produces the wound-healing effects of NCLFU.20,21 In addition to acoustical cavitation and microstreaming, the frequency resonance hypothesis also suggests a mechanism of action for the biological changes associated with NCLFU application. This theory suggests that energy from an ultrasound wave is absorbed by an individual protein molecule, which induces a conformational change. This energy may also signal transduction pathways resulting in a broad range of cellular effects, including: leukocyte adhesion, growth factor production, collagen production, increased angiogenesis, increased macrophage responsiveness, increased fibrinolysis, and increased nitric oxide levels. These ultrasound-induced cellular effects all positively impact wound healing.22-28

The purpose of this review is to investigate the efficacy of debridement capabilities of pulsatile lavage versus non-contact low-frequency ultrasound therapy as measured by healing time or wound size reduction in hospitalized patients with Stage III and IV pressure ulcers. This information will aid the clinician in determining the most appropriate treatment method for this population. The following sections synthesize the evidence for pulsatile lavage and non-contact low-frequency ultrasound therapy in terms of research design, outcome measurements, and results.

**Evidence for Pulsatile Lavage**

Researchers consider a number of outcome measures when reporting on the clinical efficacy of pulsatile lavage for the purpose of wound care, including wound size reduction and healing rate. The presence of wound and environmental bacterial contamination and tolerability of treatment are also investigated, and are discussed in later sections of this paper. Essentially two methods are used to measure wound size: linear measurement with a paper ruler, which is the most common clinical method12, or planimetry, the most accurate method for measuring wound size.14 Planimetry involves taking a digital image of the wound. The wound area is then planimetrically calculated by adding the sum of pixels within the outlined region.29 Although a standard ruler exists for measuring pressure ulcers, the Decubitus Disposable Measuring Guide (a paper ruler), this method is subjective in nature.12 Length is defined as the maximum measurement from head to toe, the width as the maximum measurement perpendicular to the length, and the depth as the measurement at the deepest part of the wound.12 Consistency is improved when the same clinician measures at every recording period. A consistent clinician is especially beneficial in improving accuracy when the measured wound area is used to generate a proportion that is indicative of healing rate.

Ho et al conducted a randomized control trial (RCT) that utilized this method for measuring wound size in combination with a volumetric measurement. This RCT performed the saline injection method to record volume of the wound, which is the gold standard.12 The ulcer is covered and sealed with an occlusive dressing, such as Tegaderm. The ulcer is then filled with normal saline using a syringe and needle injected through the occlusive dressing.12 Again, there is a subjective component to this method, i.e. discontinuing the syringe even with the epidermis surface, but the same research staff collected the volume data, thereby increasing consistency. Ho et al’s RCT found that pulse lavaged wounds decreased by 45.79% as compared to a 33% decrease in the control group. These results are strengthened by the study’s research design, which included randomization of subjects, a priori power analysis for adequate sample size, and double blinding to control confounding variables and bias.

Another RCT conducted by Shetty et al used the planimetry method and found a 14.88% decrease in wound size in the group receiving pulse lavage treatment.14 The control group receiving standard dressing changes only decreased by 7.23%.14 Healing rate was also significantly reduced in the treatment group, with an average of 6.8 days to heal compared to 14.2 days in the control group.14 This study also utilized good design including blinded evaluators and randomization. A systematic review by Leudtke-Hoffman and Schafer included research by Haynes et al. Results showed a 12.2% increase in rate of granulation tissue growth per week in wounds treated with pulsatile lavage versus a 4.8% increase in those receiving whirlpool.13 The literature shows that pulsatile lavage is effective in reducing wound size and increasing healing rate.

**Evidence for Non-contact Low-frequency Ultrasound Therapy**

The outcome measures used to assess the efficacy of non-contact low-frequency ultrasound are similar to pulsatile lavage, including wound size reduction and healing rate. Tolerability of treatment, patient-defined benefit, and quality of life are also studied, and are discussed in later sections of this paper.

 A retrospective, observational study analyzed the healing rate of 210 subjects and found that 53% of wounds treated with NCLFU healed over a mean of 147 days, whereas 32% of control group wounds healed over a mean of 134 days. The control group received only standard wound care dressing changes. NCLFU wounds experienced a faster healing; the slope of the regression line for wound healing was 1.4 in the NCLFU group vs. a slope of 0.22 for the control group.30 Another retrospective review by Bell and Cavorsi found that the median wound area of 76 wounds decreased by 79% from the start of NCLFU to the end of the treatment period.31 This evidence is slightly weakened since the researchers measured wound size with the paper ruler method. The research design also weakens the evidence since it was retrospective and did not include a control group. The fairly large sample of 76 subjects provided good evidence for frequency and duration of treatment. The authors found the median treatment time to be 4.3 weeks, mean duration of 5.1 minutes, and mean frequency to be 2.3 times per week.31

A prospective, noncomparative clinical outcomes trial measured wound size with planimetry. Wounds treated with NCLFU achieved an overall healing rate of 69% during a mean treatment time of 13 weeks, despite the loss of 7 wounds from patients lost to follow-up, death, or amputation. Removal of these cases from the data resulted in a 91% healing rate.33 An RCT by Herberger et al compared the efficacy of NCLFU to surgical debridement, the gold standard in wound debridement.32 Wound size was measured using planimetry, and there was no statistically significant difference on wound status regarding amount of necrosis, fibrin, granulation tissue and epithelialization.34 The evidence from this study is strengthened by the power calculation used to determine a necessary sample size. The research for NCLFU shows its efficacy in terms of wound size reduction and healing rate.

**Clinical Implications**

*Safety of Pulsatile Lavage*

Research also investigates whether lavage causes bacteremia. Luedtke-Hoffmann and Schafer’s review found these concerns to be unwarranted.13 Likewise, a recent outbreak of Acinetobacter species in a hospital setting assigned the blame for bacterial contamination to the administration of pulsatile lavage.35 The cross-sectional study by Ho et al. concluded that pulsatile lavage is safe when applied with proper precautions. This protocol includes: replacement of disposable suction canister inserts after each procedure, appropriate use of a splash shield to contain splashes, maintenance of close proximity of the suction tip with the wound bed during the procedure, having health care workers who perform low-pressure pulsatile lavage use personal protective equipment (ie, gowns, gloves, surgical masks, goggles), covering intravenous lines and wounds, restriction of pulsatile lavage to private rooms with easily washable surfaces and no open supply shelves, and adequate training of staff regarding infection control measures.35 Shetty et al’s RCT established that pulse lavage does reduce bacterial contamination of a wound in as little as 3 days after treatment.14

*Pulsatile Lavage Application Technique*

The Agency for Health Care Policy and Research’s Treatment of Pressure Ulcers: Clinical Practice Guideline No. 15 recommends pulsatile lavage irrigation pressures ranging from 4 to 15 psi. The agency suggests that irrigation pressures of less than 4 psi may be insufficient to remove surface pathogens and debris and that irrigation pressures greater than 15 psi may cause wound trauma and drive bacteria into wounds. The systematic review by Luedtke-Hoffmann et al confirmed this range after analyzing studies conducted by Brown et al, Rodeheaver et al, Wheeler et al, and Stewart et al, and a series of studies performed at Walter Reed Army Hospital.13 In addition, Shetty et al’s study used irrigating solution warmed to 38oC in lieu of increasing evidence on the benefits of local tissue warming to increase blood flow.14

*Practical Guidelines for NCLFU*

 Ennis et al’s intervention design utilized NCLFU therapy for 4 weeks and then altered treatment methods after this time point if no positive changes were observed.33 This time line is helpful to determine if treatment is progressing as it should. Bell et al suggest that NCLFU is only necessary until slough has been removed from the wound bed and healthy granulation tissue predominates.31

*Tolerability of PL and NCLFU*

Patients tolerated lavage well, as measured by the Visual Analogue Scale. Shetty et al found that approximately 50% of subjects reporting zero to mild pain after 3 days of treatment, compared to nearly 80% of the control group reporting some discomforting pain.14 Herberger et al also reported good tolerability of NCLFU. The researchers administered the Freiburg Quality of Life Assessment Short Version, Wounds and the Patient Benefit Index to gauge patient-defined benefit. 88% of subjects reported at least a minimal benefit from NCLFU.34 The pain rating fell between 1.5 and 1.6 points.34 The study by Bell et al also investigated pain rating and found that mean pain rating decreased by 1.8 points from the start of NCLFU to the end.31

**Limitations/Biases**

A majority of the research includes subjects with wounds of various etiologies, but some studies included only a few subjects with wounds due to pressure. Also, blinding is difficult in this area of research because the procedures are obviously different, unless the patient is sedated, which would violate ethical parameters. The articles on pulsatile lavage utilized smaller sample sizes (n=15, 28, 30), but the research designs controlled for bias and confounding variables (RCTs and cross-sectional studies). The research on NCLFU included larger sample sizes (n=23, 67, 76, 210), but the two studies with the largest samples were retrospective, observational designs. This inherently lacks control of confounding variables. Kavros et al’s study on NCLFU also attempted to provide evidence for subgroups based on wound etiology.30 These subgroups were small sample sizes and should not have been included in the conclusions of the article. Furthermore, only two articles analyzed power to determine an adequate sample size, Ho et al (PL) and Herberger et al (NCLFU).

Specifically, the study by Ennis et al reported a number of conclusions that were not statistically significant. The researchers seemed to be biased towards the efficacy of NCLFU. The subject design was also significantly flawed. Initially, all subjects were treated with NCLFU therapy; if no change was noted in 4 weeks, those wounds were treated with different modalities. These wounds were labeled as the ‘NCLFU assisted therapy’ group. The treatment method was changed because the wounds showed no improvement after NCLFU, but the authors concluded that all treatment groups showed improvement and attributed this improvement to NCLFU.33 Clearly, there are many confounding variables introduced by this study design. This evidence indicates that NCLFU may be effective in some wounds, but not in others. The authors did not report which type of wound responded to NCLFU treatment.

**Implications for further study**

The clinician faces financial restrictions when determining treatment methods. Future comparisons should include cost analyses of the two methods, including: total costs per incident, number of treatments required to achieve wound closure, and costs per treatment.13 Also, research that establishes certain wound etiologies or characteristics that warrant use of PL or NCLFU therapy would assist treament decision-making.

Longer observation periods that demonstrate total impacts on wound healing are indicated for some studies. For example, Herberger et al’s study investigated the debridement capabilities of NCLFU and surgical debridement for a period of 12 days. This design was acceptable in determining effects on wound cleanliness, but a follow-up study with a longer observation period would be beneficial.

Most importantly, a RCT is necessary to directly compare the effects of pulsatile lavage and NCLFU on wound healing. The RCT by Ho et al investigated the effects of pulsatile lavage in patients with spinal cord injury. Participants were unaware if they were receiving pulsatile lavage since the pressure ulcers were located on the sacrum, and the patients were insensate. The device was turned on to mimic the sound of the treatment.12 This study design of double blinding could be performed in order to compare efficacy of PL and NCLFU therapy.

**Conclusion/answer to PICO**

The evidence reviewed points to NCLFU as the more effective method of debridement in hospitalized patients with stage III and IV pressure ulcers. The RCT’s for each method present the most valid data for comparison. PL decreased the size of wounds by 45.79% (vs. 33% in the control)12 and 14.88% (vs. 7.23%).14 In the prospective NCLFU clinical outcomes trial, wound size decreased by 69% for a similar timeline as the PL articles. Removing the cases lost to follow-up, death, or amputation results in a 91% healing rate.29 Of most significance is the RCT that found NCLFU as effective as surgical debridement on wound status in terms of amount of necrosis, fibrin, granulation tissue, and epitheliazation. This evidence indicates NCLFU as more effective in debridement capabilities, and this information will be utilized to create a patient education pamphlet on pressure ulcer management in addition to an in-service targeting employers and employees regarding NCLFU vs. PL. This information can help employers when determining which modality to purchase for use in hospital settings.

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