

Comparison of Wound Irrigation and Tangential Hydrodissection in Bacterial Clearance of Contaminated Wounds: Results of a Randomized Clinical Study

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The process of normal wound healing involves a patterned response to tissue injury involving intricate interactions among a wide variety of cell types, structural proteins, and growth factors. These interactions frame the three recognized phases of normal wound healing — inflammation, proliferation, and remodeling. Non-healing wounds result from a disruption of this pattern and lead to prolonged hospital stays, decreased productivity, and increased healthcare costs. Many factors have been implicated in failed wound healing. Rarely is a single factor responsible for dysfunctional wound healing; usually, several interrelated factors impede the wound healing process.¹⁻³

Wound infection is the most common cause for poorly healing surgical wounds and is often complicated by disseminated infection.¹ The precise mechanism by which bacteria inhibit the wound healing process is not completely understood. Ahrendt et al² suggest that bacteria exert their primary influence by disrupting collagen metabolism, producing and secreting various toxins, enzymes, and waste material into the wound bed. *In vivo* and *in vitro* models²⁻⁴ utilizing septic rats have demonstrated a dysregulation of collagen remodeling in the presence of bacterial endotoxin. This appears to be related to a disruption in both collagen gene expression and subsequent synthesis.

Collagen remodeling is controlled by matrix metalloproteinases (MMPs), a class of proteolytic enzymes secreted by various cells in the wound bed, including macrophages and fibroblasts. A proper balance between MMPs and their associated inhibitors is necessary for normal wound healing.⁵⁻⁷ *In vitro* studies by Okamoto et al⁸ demonstrated certain bacterial proteinases alter the activation of MMPs, affecting extracellular matrix disintegration and tissue destruction in wound healing. Bacteria also inhibit proper wound healing, generating a relative hypoxia in the local wound environment by reducing the amount of oxygen available to cells responsible for immunologic function and collagen production.³ This oxygen deficit can result in impaired neutrophil and macrophage function as well as improper collagen deposition.^{9,10}

Wound cleansing, along with thorough debridement of all necrotic tissue, is essential for bacterial clearance and a prerequisite for proper wound healing.^{11,12} Animal and human studies¹³⁻¹⁵ have established that a bioburden of less than 10^5 bacteria per gram of tissue significantly increases wound healing rates of acute wounds, whether utilizing

primary or delayed closure, skin graft, or flap transference techniques.

For more than half a century, it has been well understood that thorough irrigation of wounds decreases the incidence of surgical wound infection and that this decrease is directly proportional to the volume of irrigant used.^{14,15} A second factor that determines the efficacy of irrigation is the pressure at which the irrigant is delivered to the surface of the wound.¹⁶⁻²¹ Numerous *in vivo* studies^{19,22,23} have demonstrated superior efficacy of reducing bacterial load and debris with high-powered, pulsating jet lavage in traumatic and clean-contaminated surgical wounds.

Proper irrigation of a wound includes the selection of an appropriate solution as well as the selection of a system by which to deliver that solution to the wound bed.²⁴ Most commonly, normal saline with or without antibiotic preparations is used to irrigate contaminated and infected wounds. Several methods for delivering the solution to the wound surface are available, including the use of light manual scrubbing with gauze, gravity flow irrigation, bulb syringes, piston syringes, whirlpool therapy, and mechanical irrigation.

Table 1						
	HPPWJ			PL		
Wound #	Pre-treatment	Post Treatment	% Decrease	Pre-treatment	Post Treatment	% Decrease
1	2.5 x 10 ⁷ org/g	1.1 x 10 ³ org/g	99.6	2.0 x 10 ⁸ org/g	2.3 x10 ⁵ org/g	88.5
2	4.6 x 10 ² org/g	0 org/g	100	1.6 x 10 ⁴ org/g	3.4 x 10 ³ org/g	78.8
3	3.7 x 10 ⁸ org/g	1.2 x 10 ⁵ org/g	67.6	1.2 x 10 ⁶ org/g	5.0 x 10 ⁵ org/g	58.3
4	1.8 x 10 ⁴ x org/g	6.7 x 10 ³ org/g	62.3	6.3 x 10 ⁷ org/g	2.0 x 10 ³ org/g	96.8
5	5.5 x 10 ⁵ org/g	1.25 x 10 ¹ org/g	99.8	5.0 x 10 ⁴ org/g	5.88 x 10 ² org/g	88.2
6	6.3 x 10 ² org/g	2.0 x 10 ¹ org/g	96.8	7.62 x 10 ³ org/g	0 org/g	100
7	3.75 x 10 ⁴ org/g	1.0 x 10 ⁴	73.3	8.0 x 10 ⁵ org/g	4.0 x 10 ⁴ org/g	86.7
8	2 CFU/mL	0 CFU/mL	90	2.0 x 10 ⁴ org/g	0 org/g	100
9	30CFU/ mL	3 CFU/ mL	90	20 CFU/mL	3 CFU/mL	85
10	15 CFU /mL	0 CFU/mL	100			
11	150CFU/ mL	0 CFU/mL	100			
12	100 CFU/mL	0 CFU/mL	100			

* Boxes surround wounds from the same patient.

Pulse lavage (PL), first studied more than three decades ago at the US Army Institute of Dental Research at the Walter Reed Medical Center, is a delivery system that produces a pulsatile stream of irrigant powered by an electric motor. Concurrent suction provided by the device continuously removes the irrigant as well as dislodged surface pathogens, foreign material, blood clots, and necrotic debris from the wound.²⁵⁻²⁸ Although originally described for use in oral wounds, a 1978 case study by Nourse et al²⁸ reported the use of PL for the irrigation and debridement of sacral pressure wounds. Since the 1970s, PL has gained universal acceptance for operative use in contaminated surgical wounds anywhere on the body and is now a standard of practice in the US for wound irrigation.²⁸

Recently, a new tool was developed for operative debridement of contaminated wounds. The high-pressure parallel waterjet (HPPWJ, Versajet [Smith and Nephew Inc., Largo, Fla]) utilizes a high-pressure waterjet oriented parallel to the surface of the wound capable of tangentially excising soft tissues at variable strengths. The ability of this device to excise and remove necrotic tissue is based on the Venturi effect, a special case of Bernoulli's principle,²⁹ which states that a fluid flowing through a tube that contains a constriction must increase in velocity through the constriction in order to decrease pressure and maintain the conservation of energy. Utilizing this physical principle, the HPPWJ creates a high-velocity stream of fluid oriented parallel to the wound surface capable of cutting through soft tissues.

The use of the HPPWJ for wound debridement was first described in 2005.³⁰⁻³² The removal of debris from the wound bed is accomplished in a different manner than in PL, which utilizes an external suction force. The flow of fluid through this device generates a

partial vacuum, as described by Bernoulli's principle, which acts to remove excised tissue and loose debris. Despite the relative novelty of the HPPWJ, it is increasing in popularity in the operative debridement of contaminated wounds. The purpose of this randomized, controlled clinical study was to compare the ability of HPPWJ to pulse lavage in reducing bacterial counts in contaminated and infected open surgical and traumatic wounds.

Methods

Setting. The study was conducted at the University of Medicine and Dentistry of New Jersey, Newark; and the University of California, San Diego, with the authorization of the Internal Review Board at both institutions. Both HPPWJ and PL are Food and Drug Administration (FDA)-approved for use in the management of contaminated wounds.

Patients. The patient population at both institutions present a wide variety of acute, open, surgical, and traumatic wounds. No chronic wounds such as venous or diabetic foot ulcers were included in this study.

Treatment and analysis. Each wound was randomly assigned the method of debridement via the envelope method. In each facility, patients received clear explanations of the debridement method they would receive when informed consent was obtained. Pre- and postoperative quantitative bacterial analyses were performed on contaminated wounds that required irrigation and debridement in the operating room. The microbiology laboratories at the institutions conducted all quantitative analyses and both laboratories were blinded to the method of irrigation and debridement. Because little correlation exists between bacterial counts from surface swabs and actual bacteria in the tissue levels,³² only quantitative analyses performed on tissue cultures were used in this study. Tissue samples were taken centrally from the same location in the wound immediately before debridement (in patients receiving HPPWJ treatment) or irrigation (in patients receiving PL) and immediately following completion of either debridement or irrigation. In some cases, wounds irrigated with PL also required traditional surgical debridement; post-irrigation wound culture samples were taken before surgical debridement in all cases. All post-procedure wound culture results were indexed to their corresponding pre-procedure wound culture results to yield a percentage decrease in bacterial load. This was done to account for differences in recording wound culture results between institutions. The microbiology laboratory in Newark reports wound culture results in organisms per gram of tissue; the laboratory in San Diego reports results in CFU/mL. Student's *t* test was used to determine whether the percent decrease of absolute bacterial counts in wounds differed from pre- to post-debridement between the HPPWJ and PL groups. Four wound specimens were excluded from analysis (two from each group) due to processing errors that lead to a prolonged incubation time, yielding aberrant quantitative results.

Results

Quantitative bacterial cultures were obtained from 25 traumatic and surgical wounds in 23 patients. Irrigation with normal saline was performed with either PL (n = 11) at a pressure of 40 lb per square inch (psi) or the HPPWJ (n = 14) at a power setting of 4 to 6 (correlating to 5,025 to 7,360 psi). As mentioned above, two specimens from each group were excluded secondary to aberrant specimen handling techniques, yielding a total of 12 wounds in the HPPWJ group and nine wounds in the PL group (see Table 1).

Bacterial counts in wounds debrided by the HPPWJ and PL decreased 90.8% and 86.9%, respectively ($P = 0.38$ using Student's *t*-test) (see Figure 1 and Table 2). In both groups, absolute bacterial counts decreased by an average of one to two orders of magnitude following irrigation /debridement.

Discussion

In surgical and traumatic wounds, a patient's ability to combat wound infection is greatly dependent on the number of bacteria present in the wound.^{11,12} Over the past 60 years, numerous techniques for delivering irrigant to the wound surface have been developed, ranging from the simple (eg, gravity flow and bulb syringe irrigation) to the relatively complex (eg, PL and HPPWJ).^{33,34}

Many studies have examined the efficacy of these various therapies. Therapy effectiveness has been found to be mainly dependent on two variables: the volume of irrigant used and the force with which the irrigant is applied to the wound surface. Although the use of larger amounts of irrigation solution is known to improve wound cleansing to a certain point, the optimal volume of irrigant remains controversial.³⁵⁻³⁸

The optimal pressure at which the irrigant should be delivered to the wound has been studied extensively. The US Department of Health and Human Services recommends irrigation pressures in the range of 4 to 15 psi. This recommendation is based on the findings of several studies that pressures <4 psi may be insufficient to dislodge surface pathogens while pressures >15 psi may embed bacteria and particulate matter into deeper tissues, potentially causing bacteremia and traumatic damage to surrounding soft tissue, decreasing ability to fight infection.^{16-21,24-29} Despite these recommendations, PL is routinely used for wound irrigation at pressures as high as 40 psi.

Pulse lavage is a widely used irrigation system capable of delivering large volumes of irrigant at variable pressures ranging from 6 to 100 psi. Wounds cleansed with PL in this study demonstrated a decrease in bacterial load of 86.9%. This result confirms the work of Rodeheaver et al,¹⁸ who found a 84.8% decrease in contamination of experimental wounds using PL set at a pressure of 15 psi.

The HPPWJ, which has recently received FDA clearance to be marketed for wound debridement, uses an ultra-high-pressure generator to produce a high-velocity irrigant

stream of variable intensity (up to 12,000 psi).²⁹ The stream of saline is oriented tangentially to the wound. Any tissue affected by the stream implodes and is removed from the field by the Venturi effect. Because of the orientation of the waterjet, the HPPWJ does not embed bacteria and particulate matter into deeper tissues. Consequently, and unlike irrigation methods, the HPPWJ also removes unhealthy tissue from the wound bed. Additionally, the small nozzle and facile control offered by the HPPWJ protect collateral tissues during debridement.

Although the HPPWJ has proven to be a useful tool in the debridement of contaminated wounds, it is not without limitations. Surgeons and operating room staff need to use it several times to gain a level of comfort; inexperience can cause delays in the operating room. Excessive or inappropriate use of the device can lead to unnecessary tissue excision and exposure of underlying structures.³²

In this study, use of the HPPWJ yielded a 90.8% decrease in bacterial load following the debridement of contaminated wounds. To the authors' knowledge, this is the first report to quantitatively analyze bacterial clearance using the HPPWJ; thus, no comparison to previous findings is possible.

Ultimately, no difference between HPPWJ treatment and PL was found with regard to bacterial count reduction in contaminated wounds. Both the HPPWJ and PL were found to be effective in reducing bacterial load, decreasing the quantity of bacteria found in wound tissue by 90.8% and 86.9%, respectively. It should be noted that the limited size of the study restricts its power and the possibility of a type II error cannot be excluded.

The results of this study suggest that, in addition to the potential benefit of removing necrotic tissue from the wound bed, HPPWJ treatment is equal to PL in its ability to remove bacteria from contaminated traumatic and surgical wounds, which lends support to its legitimacy for use in wound irrigation.

Conclusion

High-pressure parallel waterjet and pulse lavage are equally effective in decreasing quantitative bacterial counts in infected and contaminated traumatic and surgical wounds. Studies comparing the outcomes and cost of different wound cleansing techniques using larger sample sizes are warranted.

Dr. Granick and Dr. Tenenhaus have disclosed they are consultants for Smith & Nephew, Largo, Fla.

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