Associations Among Skin Surface pH, Temperature, and Bacterial Burden in Wounds

Khalad Maliyar, BA, Medical Student, Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada
Reneeka Persaud-Jaimangal, MD, MScCH, Clinical Coordinator, Project ECHO Skin and Wound; Research Coordinator and Special Projects, Toronto Regional Wound Healing Clinic; Adjunct Faculty, International Interprofessional Wound Care Course, Toronto, Ontario, Canada
R. Gary Sibbald, MD, DSc (Hons), MEd, FRCPC (Med Derm), ABIM, FAAD, MAPWCA, Professor, Medicine and Public Health, University of Toronto, Toronto, Ontario, Canada; Director, International Interprofessional Wound Care Course and Masters of Science in Community Health (Prevention and Wound Care), Dalla Lana School of Public Health, University of Toronto; Project Lead, ECHO Ontario, Wound & Skin Care; Previous President, World Union of Wound Healing Societies; co-Editor-in-Chief, *Advances in Skin and Wound Care*, Philadelphia, Pennsylvania

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GENERAL PURPOSE: To present a cross-sectional cohort study conducted to assess the association between wound pH, local infection, and deep/surrounding infection.

TARGET AUDIENCE: This continuing education activity is intended for physicians, physician assistants, nurse practitioners, and nurses with an interest in skin and wound care.

LEARNING OBJECTIVES/OUTCOMES: After participating in this educational activity, the participant should be better able to:

1. Synthesize the background information associated with the study assessing the association between wound pH, local infection, and deep/surrounding infection.
2. Summarize the results of the study presented here.

ABSTRACT

BACKGROUND: Wounds with a higher pH often demonstrate lower rates of healing. Local and deep/surrounding infection can be diagnosed with the validated NERDS and STONEES clinical signs, respectively. This study assessed the association between wound pH, local infection, and deep/surrounding infection.

METHODS: A 100-patient prospective cross-sectional cohort study was conducted with leg and foot wounds. Wound pH was measured using pH indicator strips. The wounds were assessed for clinical signs of local or deep/surrounding infection with the NERDS and STONEES criteria, respectively. Temperature measurements were documented with a handheld infrared skin thermometry device at the wound/periwound site, the equivalent site on the opposite side of the same leg/foot, and the wound mirror image site on the opposite leg/foot.

RESULTS: There was no significant difference in the mean wound bed pH in patients with superficial critical colonization and those without ($P = .837$). The wound and periwound maximum temperature measurements were compared with an equivalent temperature on the mirror image on the opposite leg. There was a statistically significant difference in the mean temperature (ΔT) value between patients with deep/surrounding wound infection and three or more positive STONEES criteria ($P = .002$).

CONCLUSIONS: Nontouch infrared thermometry comparing maximum mirror image wound temperatures versus the opposite extremities when combined with two or more other STONEES criteria is a significant indicator of deep and surrounding infection. Surface wound bed pH indicator strip measurements do not correlate with local wound infection using the NERDS criteria.

KEYWORDS: chronic wound, contralateral, infection, infrared, nonhealing wound, pH, temperature, thermometry

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INTRODUCTION

As the global population ages, there is a projected increase in chronic wounds with an attendant decrease in affected patients' quality of life.[1] In developed countries including the US and Scandinavia, 1% to 2% of the population will experience a chronic wound in their lifetime.[2] This resource-intensive healthcare burden is a challenge to providers and an economic burden on the healthcare system. Further, there are associated health sequelae (eg, foot amputation) and complications, including deep and surrounding infection.

Current diagnostic techniques for the clinical assessment of wound infection include the wound's observable appearance (eg, surrounding cellulitis, increased discharge, odor, etc), usually accompanied by bacterial swab culture of the wound surface exudate or tissue biopsy for bacterial culture to identify the organisms present and their sensitivity.[3] Objective clinical signs of the wound site infection can guide healthcare providers' diagnosis and treatment.[4]

Sibbald et al[5] developed a validated clinical tool to standardize the diagnosis of superficial critical colonization (NERDS criteria) and deep chronic wound infection (STONEES criteria). The NERDS mnemonic is as follows: **N**onhealing (length × width is relatively static over 2–4 weeks), **E**xudate is increased, **R**ed friable granulation on the wound surface, **D**ebris or dead cells on the wound surface, and **S**mell that usually indicates the presence of Gram-negative or anaerobic organisms. Any three or more signs are diagnostic of local infection (with a sensitivity of 73.3% and specificity of 80.5%).[6]

The STONEES mnemonic consists of seven clinical signs: **S**ize enlargement, **T**emperature increase of 3° F or more versus the opposite limb mirror image temperature, **O**s (bone exposed or direct probing), **N**ew areas of break down on the wound margin, **E**xudate increase, **E**rythema and/or **E**dema (usually indicates cellulitis), and **S**mell. Any three of the seven STONEES criteria are diagnostic of deep and surrounding infection (with a sensitivity of 90% and specificity of 69.4%).[6] Patients who have been diagnosed with local infection should be treated with topical antiseptic dressings (eg, silver, iodine, chlorhexidine/polyhexamethylene biguanide, or methylene blue/crystal violet nonrelease foam). These dressings may be used in conjunction with autolytic debridement and moisture management. Wounds with deep and surrounding infection should be treated with systemic antimicrobials (oral or parenteral).

There is a need for noninvasive assessment approaches to determine deep and surrounding wound infection and avoid overuse of systemic antimicrobial agents that can promote the emergence of resistant organisms.[7] The use of antibiotics is often indiscriminate and a result of poorly defined clinical parameters.[8] Two parameters that have been given more attention in the context of chronic wounds are wound bed pH and periwound skin surface temperature.[6]

The pH of intact normal skin is acidic, ranging from 4.2 to 5.6.[9] This low pH imparts the skin with antimicrobial defense, impeding pathogenic bacteria such as *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Streptococcus pyogens*.[10] In contrast, chronic wounds often have an elevated alkaline environmental range of 7.2 to 8.9.[11] Wounds with a higher pH have demonstrated lower rates of healing compared with wounds whose pH is closer to neutrality.[10] Greater wound alkalinity is associated with an optimal environment for various bacterial species to grow and survive.[12]

Local elevation in skin temperature may be associated with periwound deep and surrounding infection, deep inflammation/trauma (acute Charcot joint), or unequal vascular supply.[13] Chronic wounds that are infected typically take longer to heal because infection impairs the wound healing process.[14] For example, Armstrong and Lavery[15–19] verified that regions of the neuropathic foot in patients with diabetes who have greater skin temperature are more likely to ulcerate from repetitive trauma.

There are many devices used to measure periwound and wound surface temperatures. Nontouch infrared thermometers are an accurate and simple method of measuring periwound skin temperature.[13] Previous studies assessing wound temperature tend to measure temperatures at the wound site and the corresponding contralateral limb at the exact same anatomical position. These studies have not recorded temperature measurements of the wound site and its mirror image on the same body region (eg, front and back of the calf vs the opposite calf) as a monitor for ongoing wound status.[6]

Objective

The objective of this study was twofold. The primary objective was to assess the association between wound pH and the extent of local infection using the NERDS criteria. The second primary objective was to determine the relationship between the temperature of the wound bed, its mirror image on the opposite side of the same leg, the mirror image on the contralateral limb, and the STONEES criteria.

MATERIALS AND METHODS

This study received ethics approval from the Institutional Review Board Services (Aurora, Ontario, Canada). Patient visits were conducted at the Toronto Regional Wound Clinic, an outpatient dermatology and wound clinic. Written informed consent forms outlining the study purpose and need for photo documentation were signed by the patients.

A prospective cross-sectional cohort study was conducted on patients 18 years or older who attended the clinic between June 2018 and August 2018. Patients with at least one chronic, nonhealing leg or foot ulcer of various etiologies were included in the study. Patients were enrolled by convenience sampling. The following key patient data were collected:

- Demographic data: sex, date of birth, age, weight, height
- Clinical data: allergies, diabetes mellitus type 1 or 2, coexisting illnesses, smoking status/pack-years, alcohol use, medications, wound description (duration, location, diagnosis), pain
- Physical examination: especially the legs, including presence of a pulse, audible handheld Doppler for monophasic or multiphasic sounds, and chart review of previous ankle-brachial pressure index and other key data.

Procedure

Each patient's wound was exposed, and he/she then rested in a seated position for at least 2 minutes to allow for any heat collected under the occlusive dressing to evaporate. Then, the wound was evaluated by one of the study researchers to assess the NERDS and STONEES criteria. Friable granulation was assessed by gently manipulating the surface and wound base with a sterile instrument and observing any signs of bleeding. The wound size was measured using the longest length and widest width at right angles. The existing documentation was checked for previous wound size measurement. The exudate levels were recorded by examining the removed wound dressing. If the wound exudate stained more than 50% of the inner dressing, then an increased presence of exudate was recorded. The researchers then assessed the depth of the wound and the potential for bone exposure with the use of a sterile cotton applicator.

Thereafter, the pH of the wounds was measured using two pH indicator strips of pH 4.0 to 7.0 and 6.5 to 10.0. The accuracy of the indicator strips was first confirmed by testing it against a standard solution of known pH. A new strip was pressed against the wound bed for five seconds. The strip was then removed, and 30 seconds later, the color of the strip was compared with a color code chart on the package and the result was recorded.

As a final step, under consistent ambient air room temperature, temperature measurements were made using one of two infrared skin thermometry devices.[20] The measurements were repeated using both thermometers at three distinct areas, all at a distance of 1 cm above the skin: (1) the target (wound site), (2) the matched anatomical site on the opposite side of the same leg/foot, and (3) the equivalent contralateral (control) wound site on the opposite leg/foot (ie, mirror image). The patient's temperature at the wound site was subtracted from the temperature of the matched anatomical sites. The devices did not contact the wound bed. The whole-wound and periwound zigzag scanning method determined the maximum temperature by continually activating the thermometer during the entire scanning procedure.

Wounds were subsequently irrigated and then cleansed with either normal saline or water, depending on the wound type, until all visible debris was washed away. The pH and maximum temperatures were remeasured using the same methods.

Data Analysis

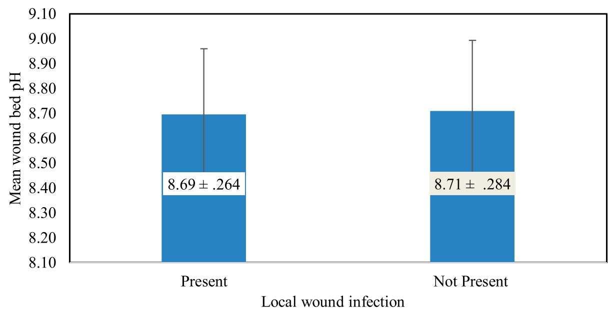
The temperature difference (ΔT) was set as a binary variable of either yes/no whether the difference reached a threshold of 3° F or higher. Individuals were considered to have a positive NERDS and STONEES status if they were positive for three or more of the NERDS parameters or STONEES parameters, respectively. Independent-sample t tests were conducted to compare wound bed pH in individuals who tested positive for NERDS and those who did not. Another independent-sample t test was conducted to compare ΔT in individuals who tested positive for STONEES and those who did not. A third independent-sample t test was conducted to compare wound temperature site and the matched anatomical site on the same leg in patients who tested positive for STONEES. A final independent-sample t test was performed to compare the ΔT between the wound site and the temperature of the matched anatomical site on the opposite side of the same leg/foot in patients with and without deep wound infection. All relevant calculations for pH and temperature measurements were recorded for both pre- and postwound cleansing, because cleaning solutions (ie water, saline, or a 0.05% solution of sodium hypochlorite) could potentially alter values. $P < .05$ was considered statistically significant.

RESULTS

A total of 100 patients participated in the study. The following demographic variables were collected:

- Sex: 59 men, 41 women
- Age: 39 to 97 years (mean, 69.24 [SD, 12.561] years)
- Weight: 43.09 to 199.98 kg (mean, 91.10 [SD, 3.16] kg)
- Height: 139.70 to 193.04 cm (mean, 171.19 [SD, 1.04] cm)
- Body mass index: 16.51 to 68.5 kg/m^2 (mean, 30.84 [SD, 10.68] kg/m^2)
- Wound duration: 14 days to 24 years (mean, 38.16 [SD, 5.28] months)
- Diabetes mellitus (both types): 31%
- Nonsmokers: 59%
- Wound location: 48% ankles/malleoli, 28% on the shin, 26% on the plantar foot/toes
- Positive NERDS criteria: 24%
- Positive STONEES criteria: 26%

Figure. MEAN WOUND BED PH OF INDIVIDUALS WITH AND WITHOUT LOCAL WOUND INFECTION ($P = .84$)



There were no changes seen between the pH and temperature measurements before and after wound cleansing. (All results shown are prewash measurements.) There was no significant difference in the mean wound bed pH in patients with local infection (pH 8.69 ± 0.264) and those without (8.71 ± 0.284, $P = .84$; Figure). There was a statistically significant difference in the mean temperature (ΔT) value between patients with deep/surrounding wound and those without ($P = .002$). There was no significant difference in the matched wound anatomical site temperature measurement on the same leg/foot between patients with and without positive STONEES ($P = .164$). There was no significant difference in temperature surface thermometry measurements alone between the wound site and the temperature of the matched anatomical site on the reverse side of the same leg/foot in patients with and without deep wound infection ($P = .507$; Table).

DISCUSSION

Chronic nonhealing wounds affect approximately 2% of the population.[21,22] Delayed and impaired healing of chronic wounds can lengthen patient unease and discomfort, heighten the risk of complications, and be a tremendous burden to the healthcare system.[14,23] Accurately diagnosing infected chronic wounds and prescribing appropriate antibiotics remain a challenge in the field of wound management. Current clinical assessment of the wound bed is dependent predominantly on subjective interpretation with minimal objective analysis.[24] The importance of accurate wound infection diagnosis is underscored by concerns about antibiotic resistance, inappropriate antibiotic prescribing, and adverse effects of treatment.[25] There is a need for simple, brief, inexpensive tests that provide objective, real-time identification of wound infection in the clinical setting. This study explored the use of pH indicator strips and handheld nontouch infrared thermometry devices as objective instruments for use in routine clinical practice.

This study demonstrated that the use of pH indicator paper, also known as litmus paper, to measure wound bed pH did not statistically distinguish patients with and without local bacterial infection as defined by the three or more NERDS criteria. pH levels on the wound surface may not reflect the pH deeper in the wound, and the strips may not be an accurate measurement when compared with other forms of instrumentation. The use of cleansing solutions or dressings may have also influenced the surface pH of the wounds in this study.

The growth of wound bed bacteria has been reported to increase the normally acidic skin surface pH to a more alkaline level.[26] Wound surface bacteria release an ammonia byproduct that can impede the oxygenation of the wound tissue. This occurs by limiting the release of oxygen from oxyhemoglobin, creating an optimal environment for further bacterial growth.[11] Ono et al[27] reported that documenting consecutive pH measurements using litmus paper demonstrated an upward alkaline change in wound pH. However, that patient population was limited to those with second-degree burns, whereas this study had wounds of various etiologies. More research needs to be conducted to identify the relationship between wound pH and infection if pH measurement is to be used as a supplement to infection diagnosis.

Skin surface thermometry can measure temperature increases from deep and surrounding wound infection as well as deep inflammation (eg, Charcot joint).[28] Local ischemia or decreased arterial circulation may lead to a

Table. MEAN TEMPERATURE DIFFERENCES IN PATIENTS WITH AND WITHOUT DEEP WOUND INFECTION

	Three or More STONEES Criteria (n = 26)	Fewer Than Three STONEES Criteria (n = 74)	P
ΔT_1: Wound temperature difference—contralateral site temperature on opposite leg/foot	+2.95° F ± 3.48° F (–16.14° C ± –15.84° C)	+0.51° F ± 3.33° F (–17.49° C ± –15.93° C)	.002
Temperature of the matched anatomical site on the opposite side of the same leg/foot	+91.95° F ± 1.68° F (+33.31° C ± –16.84° C)	+91.08° F ± 2.98° F (+32.82° C ± –16.12° C)	.164
ΔT_2: Wound temperature difference—temperature of the matched anatomical site on the opposite side of the same leg/foot	+0.13° F ± 2.50° F (–17.71° C ± –16.39° C)	–0.27° F ± 2,62° F (–17.93° C ± –16.32° C)	.507

decrease in skin surface temperature. This study had an individual factor analysis that demonstrated an elevated periwound temperature was eight times more likely to be associated with deep and surrounding infection compared with a 2.76 to 5.71 times factor for each of the other STONEES criteria.

Patients with a positive STONEES status in this study had a temperature difference between the wound and the contralateral site on the opposite limb of 2.95° F ± 3.48° F. These findings are similar to data from a clinical trial performed by Armstrong et al,[29] reporting a temperature difference of 2.81° F ± 5.75° F between diabetic foot ulcers of limbs that were infected and the matched anatomical site on the contralateral foot. This suggests that having quantitative skin temperature measurements (performed with handheld noncontact infrared thermometry) during routine wound assessment can support an early diagnosis and treatment of deep and surrounding infection. Periwound skin temperature measurements provide an immediate clinical indicator of deep/surrounding wound infection when combined with two or more other STONEES criteria.

Statistical analysis did not show a significant relationship between the periwound skin temperature and the temperature of the matched anatomical site on the reverse of the same leg/foot in patients with or without STONEES criteria for deep and surrounding wound infection. This suggests that measuring the temperature on the opposite side of the same limb does not provide an accurate measurement in all patients probably because of circumferential spread of the increased temperature to adjacent skin surface. In general, temperature measurements of any site of the body are often comparable to a symmetrical contralateral site.[30] However, there is a paucity of literature that reports on the ΔT between anatomical sites and their mirror image on the same leg. Factors such as location on the body, compromised blood flow, and ambient temperature are all factors that can affect local skin temperature.

CONCLUSIONS

Noncontact infrared thermometry comparing maximum temperatures of mirror image of a wound on the opposite extremity, when combined with two or more other STONEES criteria, is a significant indicator of deep and surrounding infection. However, noncontact infrared thermometry of the wound/periwound skin compared with the opposite side of the same extremity is not, alone or when combined with two or more other STONEES criteria. Periwound skin temperature and temperature measurements of the reverse side of the same extremity should be used with caution because a temperature increase can travel circumferentially. Further, measuring wound bed pH using surface pH indicator strips does not provide an accurate or useful indicator of local wound infection.

PRACTICE PEARLS

- Wounds with a higher pH often demonstrate lower rates of healing with enhanced pathogenic bacterial growth.
- Local and deep/surrounding infection can be diagnosed with the validated NERDS and STONEES clinical signs, respectively.
- Noncontact infrared thermometry comparing wound temperatures versus the opposite extremities when combined with two or more other STONEES criteria is a significant indicator of deep and surrounding infection.
- Surface wound bed pH as assessed by indicator strip does not correlate with local wound infection using the NERDS criteria.

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