The relationship between periwound skin condition and venous leg ulcer chronicity

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What is already known about this topic:

- Prognostic factors impairing the healing of venous leg ulcers include increased age, large wound size, longer wound duration, high body mass index and reduced mobility.
- Periwound condition is also associated with venous leg ulcer healing and is an important part of overall wound assessment and management.
- Periwound assessment currently relies on subjective clinician assessment.
- There are diagnostic devices used in cosmetics and dermatology that can objectively and reliably measure skin hydration and erythema and these devices could enhance periwound assessment.

What this manuscript contributes:

- Investigating the agreement between clinician visual periwound assessment and measurements using an objective skin diagnostic device.
- Explore associations between clinician visual periwound assessments, objective periwound assessment using a skin diagnostic device and venous leg ulcer size and duration.

Keywords: Skin assessment, wound, epidermal hydration, epidermal erythema, clinician assessment.

ABSTRACT

Clinicians assess the periwound of venous leg ulcers (VLUs) to optimise their management and treatment. Yet, there has been little research on whether undesirable periwound conditions such as maceration, dehydration and erythema are associated with VLU chronicity and non-healing. This study addressed the gaps in the literature by exploring associations between clinician visual periwound assessment, objective periwound assessment using a skin diagnostic device and VLU chronicity. This study also explored the agreement between clinician assessment and objective measurements of periwound status. In total, 16 VLU periwound were assessed. No association was found between undesirable periwound conditions such as maceration, dehydration or erythema and longer wound duration and wound size. This study identified a significant relationship between clinician and objective assessment of dehydration suggesting that current visual assessment of periwound dehydration may accurately reflect VLU periwound dryness. However, it is recognised that mechanisms underlying periwound redness are complex and there is difficulty ascertaining if periwound redness is truly detrimental for wound healing. Overall this study provides a preliminary insight into the relationships between periwound hydration and erythema and VLU chronicity and can inform future research to improve wound assessment and management.

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INTRODUCTION

Wounds form as a result of disruption to skin integrity, organ tissues or mucosal surfaces[1]. Venous leg ulcers (VLUs) are a type of wound associated with chronicity and non-healing, and generally occur as a result of venous hypertension, venous occlusion or an ineffective calf muscle pump[2]. Although VLUs affect people of all ages, they are more common amongst the elderly, with an estimated 0.33% of the Australian population aged 60 and above having one or more VLU, significantly impacting the population[3]. VLUs are also associated with delayed healing and recurrence rates are up to 70%[2]. In Australia's ageing population, it is likely that health care costs associated with VLUs will rise[4]. In addition to the financial toll of these wounds, VLUs also impact an individual both physically and emotionally, causing impaired mobility, pain, depression, embarrassment and helplessness[5,6].

A thorough VLU assessment is undertaken to facilitate timely healing and the best outcomes for clients and takes into account key factors known to effect wound healing, including increased age, high body mass index (BMI), reduced mobility[7-9], longer wound duration and larger wound size[10]. The periwound — the skin within four centimetres from the wound edge and the wound edge[11] — is considered an important aspect of VLU assessment[2].

The theory of moist wound healing advocated by Winter[12], proposes that wounds associated with excess and insufficient moisture will experience impaired healing and deterioration. With relevance to the VLU periwound, it is possible that macerated or dry periwound skin may be indicative of excess or deficient wound bed hydration associated with poor VLU healing outcomes. Previous research studies have examined the effect of promoting reducing VLU maceration on wound healing and found that when moisture was reduced at the VLU wound bed and periwound, wounds were able to reduce in size and, in some studies, completely heal[13-15]. Similarly, Hunter and colleagues found that participants using a silicon-containing application to reduce VLU periwound dehydration experienced a greater reduction in wound size and circumference compared to another group of participants with VLUs who did not use this application[11]. Evidently, it is important to ensure moisture balance at the periwound and wound bed to ensure optimal healing outcomes for VLU wound progress.

Prolonged inflammatory processes and infections are also known to be associated with impaired VLU healing[16,17]. Prolonged inflammation leads to degradation of the extracellular matrix (ECM) through increased pro-inflammatory mediators inhibiting cellular migration at the skin-wound junction and further activates inflammatory processes. These underlying inflammatory processes and infections at the VLU periwound may be observed as erythematous periwound skin[18]. Previous studies have found that a VLU periwound with increased inflammatory mediator presence is associated with longer wound duration and non-healing[16,17].

Given prospective associations between VLU periwound skin condition and healing, accurate assessment of the presence and severity of these conditions are essential for effective VLU management. Currently, visual assessment of periwound skin includes assessing skin redness for erythema, whitish skin as presence of maceration and observing for scaly, dry skin as dehydration. However, the reliability and methods of current VLU periwound skin assessment practices have not been established. Additionally, subjectivity in assessing periwound maceration due to the similar appearance to fungal infections have been noted[19]. Similarly, erythema assessment characterised by redness may be subjective and influenced by skin pigmentation, increasing the subjectivity of erythema assessment[19]. Other non-invasive instruments with the capacity to measure skin hydration, erythema and lipids and provide objective measurements have demonstrated reliability in the cosmetic and dermatologic fields[20]. It is possible that these devices can be used for objective periwound skin assessment in VLU management.

The aim of this study was to determine if VLU periwound skin condition as assessed by an objective device; the SD202 (Courage+Khazaka electronic GmbH), was associated with VLU chronicity. This study also sought to determine if VLU periwound skin condition assessed by the SD202 was associated with clinician visual assessment of the periwound.

METHOD

Participants of this study were recruited from an outpatient clinic at a major metropolitan public hospital in Melbourne, Australia between May and August in 2014. Participation in this study was restricted to patients older than age 18 and clinically diagnosed with VLUs. Ulcers of venous aetiology were determined by consulting clinicians who checked patient venous duplex scan results and clinical notes. Written informed consent to participate in the study was provided by the patients prior to the start of data collection. The target sample size for this study was determined based on simple power analysis for each SD202 parameter (hydration, erythema) to be studied. The minimum sample required to analyse findings of the three continuous measurements from the SD202 probes was $n = 30$[21].

EQUIPMENT AND DATA COLLECTION TOOLS

SD202 Skin measuring device

Objective measures that assess skin lipids, hydration and erythema are well-established in the field of cosmetics and dermatology. In this study, VLU periwound skin was assessed using the SD202 Skin Measuring device (Courage+Khazaka electronic GmbH) that measures biophysical properties such as hydration, lipids, melanin and erythema. The SD202 comprises three measuring probes; Sebumeter, Corneometer and Mexameter[22]. In this paper, only the Corneometer and the Mexameter readings were relevant.

The Corneometer (Courage+Khazaka electronic GmbH, Germany) has been known to accurately and reproducibly assess epidermal hydration based on capacitive measurements of a dielectric medium; the skin stratum corneum[23,24]. This method is based on the direct relationship between the skin's electrical property and epidermal hydration[25,26]. Conductivity of the epidermis reflects variations in the water content, which is converted to arbitrary units ranging from 0 to 99. In arbitrary units, a 0 score indicates that the skin is completely dehydrated and 99 indicates that epidermal skin is extremely hydrated and saturated. The probe exerts constant pressure on the skin surface using a spring system to ensure reproducible measurements[26] and covers an area of approximately 40 mm^2. Care was taken to avoid positioning the Corneometer over hairy skin and topical applications, as measurements may be inaccurate under these conditions[22]. Additionally, it was also noted that at higher hydration states, the Corneometer may be less sensitive[22,37].

Table 1: Mean wound size and duration and clinician visual assessment

	Clinician assessment		*t* (14)	*p*	*d*
	Yes	No			
Duration (months)	**M (SD)**	**M (SD)**			
Maceration	24.9 (17.7)	16.1 (14.8)	1.04	.317	0.56
Dehydration	19.9 (14.7)	17.1 (18.5)	0.34	.739	0.18
Erythema	13.7 (11.0)	25.5 (19.1)	1.56	.141	0.83
Size (cm^2)	**M (SD)**	**M (SD)**			
Maceration	15.3 (18.1)	8.4 (7.5)	1.12	.282	0.60
Dehydration	7.8 (7.8)	15.1 (16.1)	1.22	.242	0.65
Erythema	10.1 (7.6)	11.1 (16.2)	0.16	.874	0.09

Note: M=mean; SD=standard deviation; t=t-value; p=significance value; d=Cohen's d

Epidermal erythema was assessed using the Mexameter probe (Courage+Khazaka electronic GmbH, Germany). The Mexameter uses photodetection to measure skin colour through light of different wavelengths reflected by the skin[27]. Light-emitting diodes arranged at the detector circumference emit light of three wavelengths: 568 nm (green), 660 nm (red) and 880 nm (infrared). Haemoglobin absorbs red and green light and the intensity of light absorbed is measured by the Mexameter and converted to a numerical scale based on arbitrary units ranging from 0 to 99. In arbitrary units, a 0 score indicates that there is a complete absence of any erythema or redness of the skin and 99 indicates that the skin is extremely red. The probe exerts constant pressure on the skin surface using a spring system to ensure reproducible measurements[28] and measures an area of approximately 20 mm^2. A foam light mask was placed around the detector surface to prevent ambient light from falling onto the skin and confounding measurements[22].

DATA COLLECTION

Post-cleansing with chlorhexidine gluconate containing solution, VLU periwound skin of all study wounds was assessed using the SD202. Three consecutive measures were taken at four locations around the VLU; one centimetre from the topmost (0°), leftmost corresponding to the participant's left hand side (90°), bottommost (180°) and rightmost (270°) wound edge. Clinic staff providing the wound care assessed the VLU periwound. Specifically, clinicians identified the presence or absence of periwound maceration, dehydration and/or erythema using a dichotomous scale (yes/no). Wound size and depth was measured using the Visitrak system[29]. Where there were two or more wounds present at the point of assessment, the larger wound was considered the 'study wound'. Patients were also asked to report information about their medical history, wound duration and weight and height necessary for the calculation of a BMI. All data were recorded on hard copy paper forms.

DATA ANALYSIS

Data were analysed using IBM SPSS Statistics, Release Version 21.0.0. Frequencies and descriptive statistics were performed and the data were assessed for normality, linearity and homoscedasticity to determine the appropriateness of the intended statistical tests. Normality of the distribution was tested by the Kolmogorov-Smirnov Goodness of Fit test[30]. Based on evidence in the literature, due to a lack of variability when calculating an VLU chronicity index[10], wound duration and size were analysed as separate variables.

Pearson's product moment correlations were calculated to determine the relationship between VLU duration and size, clinician visual periwound skin status, and SD202 periwound skin status. Correlation coefficients can range from 1.0 (perfect positive correlation) to –1.0 (perfect negative correlation) with a correlation of 0 indicating the absence of a relationship between the variables[31]. Correlations were also conducted between SD202 measures and wound duration and size. Mean comparisons between wound duration and size, and clinician assessments and SD202 assessment were also conducted using independent sample t-tests where it was necessary to compare two groups of independent data.

RESULTS

In the 12-week recruitment time frame, 16 participants were recruited. None of the participants withdrew from the study and there was no missing data. An equal number of males (56.3%) and females (43.7%) participated in this study who had a mean age of 69.3 (±17.0) years. Wounds assessed in this study had a mean

duration of 18.9 (±15.7) months and a mean area of 10.6 (±11.6) cm^2. For the 16 VLUs assessed, the SD202 hydration score ranged from 0.0 to 75.8 arbitrary units (a.u.) and the mean score was 24.8 (±29.1) a.u. SD202 erythema scores ranged from 25.0 to 58.5 a.u., with a mean of 39.2 (±9.8) a.u. Clinicians also assessed 31.0% of VLU periwounds as macerated, 62.5% as dehydrated and 56.3% as erythematous.

Clinician assessment and wound characteristics

Small non-significant correlations were found between wound duration and clinician assessment of periwound maceration (r= –298, p= .262) and dehydration (r = –.109, p= .689). This demonstrates that longer wound duration had limited association with clinician assessed periwound maceration and dehydration. On the contrary, a moderately positive association (r= .350, p=.184) was found between clinician assessed erythema and wound duration. Similarly, non-significant correlations (r= –246, p= .358) were found between wound size and clinician assessed periwound maceration and dehydration (r= .350, p= .184). Clinician assessed erythema was not found to be associated with wound size.

Mean wound duration and wound size were compared between periwounds that were assessed by clinicians as macerated, dehydrated or erythema and those not assessed as macerated, dehydrated or erythema to further examine if clinician visual periwound assessment was associated with longer wound duration and larger wound size (see Table 1).

Sample means presented in Table 1 show that periwounds assessed as macerated, dehydrated and erythematous had similar wound size and duration to those not categorised as macerated, dehydrated and erythematous. Given the small sample size, the effect size of the difference in means was further appraised if the lack of significance related to limited power or modest coefficients. The effect size ranged from small to moderate and did not reflect considerable strength in the differences between means (see Table 1).

SD202 measures and wound characteristics

Pearson's product-moment correlations were performed to confirm the strength and direction of the associations between SD202 periwound measures and wound duration and wound size. Non-significant correlations were found between SD202 hydration scores and wound duration (r= –.177, p= .513) and wound size (r= .167, p= .535). Similarly, no association was found between SD202 periwound erythema scores and wound duration (r= –.217, p= .419) or wound size (r= –.217, p= .419)

Clinician assessment and SD202 VLU periwound assessment

A statistically significant, positive correlation was found between clinician assessment of dehydration and lower SD202 hydration scores (r= .891, p <.001). Clinician visual assessment of maceration

Table 2: Mean SD202 scores and clinician visual assessment

	Clinician assessment		*t* (14)	*p*	*d*
	Yes	No			
SD202 hydration (a.u.)	**M (SD)**	**M (SD)**			
Maceration	34.2 (36.8)	20.6 (25.9)	0.85	.408	0.46
Dehydration	5.4 (9.2)	57.3 (19.4)	7.34	<.001*	3.92
SD202 erythema (a.u.)	**M (SD)**	**M (SD)**			
Erythema	36.2 (8.1)	43.1 (10.9)	1.46	.165	0.78

Note: a.u.=arbitrary units; M=mean; SD=standard deviation; *t*=t-value; *p*=significance value; *d*=Cohen's d

* $p < .001$

was found to have slight associations with higher SD202 hydration scores but failed to achieve statistical significance ($r = -.222$, $p = .408$). A non-significant relationship was found between clinician assessment of periwound erythema and higher SD202 erythema scores ($r = .364$, $p = .165$). Inconsistent with what was expected, this finding suggests a moderate association between clinician assessment of periwound erythema and lower SD202 erythema scores. Independent sample t-tests were performed to compare mean SD202 scores between periwounds visually assessed by clinicians as macerated, dehydrated or erythematous compared to those not appraised as macerated, dehydrated or erythematous (see Table 2).

There was a statistically significant difference between mean SD202 hydration scores for periwounds assessed as being dehydrated ($M = 5.35$, $SD = 9.2$) and periwounds not clinically assessed as dehydrated ($M = 57.3$, $SD = 19.4$; $t(14) = 7.34$, $p < .001$), a difference that exhibited a large effect size ($d = 3.92$). However, differences in mean SD202 scores and visual assessment of maceration and erythema did not achieve statistical significance.

DISCUSSION

This study investigated the relationship between VLU chronicity and periwound status using an objective diagnostic device and clinician assessment. This study also examined associations between clinician assessment and SD202 measurements. Given the lack of variability in a VLU chronicity index[10], wound healing outcomes were represented in this study by two separate variables; wound duration and size.

Clinician periwound assessment was not found to be associated with wound duration and size. Yet, it is known through the literature that periwound maceration, dehydration and erythema are associated with delayed and non-healing VLUs and that appropriate management of these conditions can contribute to wound healing progress[15-17,32]. This study found that clinicians assessed more than half the VLU periwound as dehydrated and a third as macerated. The range of the SD202 hydration measurements (0.0 to 75.8 a.u) also reflected these high and low VLU periwound hydration states. However, the lack of significant associations between VLU periwound and wound outcomes may be attributed to several reasons. First, previous studies investigating VLU periwound maceration and dehydration did not explore associations with VLU chronicity but instead considered the impact of dressing products on the periwound and wound healing[14,15,32,33]. Though these studies demonstrated that dressing and product choices successfully decreased periwound maceration and dehydration leading to improved wound outcomes, these measures are at best a surrogate indicator and not a direct means of measuring VLU chronicity. Instead, the current study focused on direct associations between periwound maceration and dehydration and VLU chronicity. Additionally, due to a small sample size the original Margolis' model predicting wound chronicity based on a two item count model that is a sum of one point each if the wound is larger than 10 cm^2 and older than 12 months was unable to be used[10]. The count model consists of categories associated with a percentage likelihood of non-healing and placements into these categories are dependent on wound size and duration[10]. It is possible that wound duration and size considered in isolation, lacks the predictive power of VLU chronicity and weakened the associations with visually assessment periwound hydration.

Objective and subjective measures of skin redness were also considered in the current study for their association with each other and with wound duration and size. An excess of pro-inflammatory mediators result in prolonged inflammatory processes, and as such it suggests that visual assessment of VLU periwound erythema, an established clinical sign of inflammation and infection, would reflect inflammatory processes occurring at the VLU periwound[16,17]. However, based on the study results, it is possible that observations of increased periwound erythema might not be associated with inflammatory processes but instead with better perfusion and wound healing. The moderate association found between smaller wound sizes and higher SD202 erythema scores support this

interpretation. It is known that as VLUs heal, granulation tissue forms and re-epithelialisation occurs, which increases VLU perfusion[34-36]. One study found that as VLUs progressed through stages of healing, perfusion as assessed using a Laser Doppler was found to increase[34]. These findings suggest that as VLUs heal and granulation tissue forms, tissue perfusion increases correspondingly. Hence, it is recognised that there are complexities in understanding what VLU periwound redness indicates. Given these complexities, high erythema scores could equally reflect a good wound healing sign such as increased perfusion or compromised healing associated with infection. Future studies may benefit from determining the degree or quality/nature of tissue perfusion in assessing erythema caused by inflammatory responses.

The current study also provided some initial insights into the validity of clinician assessment of VLU periwound status. In relation to clinician assessment of dehydration and lower SD202 hydration scores, clinician assessment results were significantly supported by SD202 measurements. In contrast, only a slight agreement between clinician assessment of periwound maceration and higher SD202 hydration scores was found. Additionally, there was a lack of association found between clinician assessment of erythema and lower mean SD202 erythema scores.

There were previous studies examining the visual assessment of dehydrated skin. Heinrich and colleagues found that there was an acceptable level of agreement between expert and lay person assessment of dry skin[37]. The similar ability for experts and lay persons to assess dry skin suggest that dry skin assessment generally has little variation even amongst people with the expertise of skin assessment and the lay person. It might be that the assessment of dehydrated skin is less challenging than thought. This agrees with the study findings that clinician assessment of skin dehydration was strongly associated with lower SD202 hydration scores, demonstrating some associations even between objective and subjective means of assessment.

The agreement between clinician assessment of periwound skin dehydration and SD202 measurements was not replicated in assessment of VLU periwound maceration. Difficulties in periwound assessment have been documented in other studies that found that periwound maceration assessment is difficult, maceration can be easily undetected and that white macerated tissue may be confused with new epithelial tissue or fungal infections[11,19]. Alternatively, the poor association between clinician assessment of periwound skin maceration and SD202 measurements could also be attributed to poor sensitivity of the Corneometer in assessing higher hydration states noted in previous studies[24,38]. It is unclear if the lack of association found between clinician assessment of VLU periwound maceration and SD202 measurements may be attributed in part to these challenges faced in VLU periwound assessment of maceration.

Another notable finding in this study is that periwounds assessed as erythematous had lower SD202 erythema scores. This unexpected finding may be attributed to how colour assessment is a subjective process influenced by different factors such as changes in surface positions and illuminants[39], whether scenes are viewed in three dimensions[40] and dynamically changing colours around the object being viewed[41]. In considering the impact of these findings on colour assessment, variability is expected in skin colour assessment by different clinicians and even for the same assessor. However, there is evidence suggesting that colour assessment can be improved using tools such as skin colour charts[42,43]. Yet, as mentioned previously, it is also understood that although accurately assessed, VLU periwound erythema is influenced by many complexities. Although periwound redness may be present, there is difficulty determining if it is advantageous for wound healing or not.

Overall, the need to use wound duration and size as a measure of VLU chronicity is a limitation of the study. It was originally intended that VLU chronicity be assessed using the count model suggested by Margolis and colleagues[10]. However, there was insufficient variation in the index scores to enable statistical analysis. The lack of significant findings in this study might be attributed to the use of wound size and duration as separate variables to uniquely represent VLU chronicity. The cross-sectional nature of this study made it impossible to assess wound size reduction or wound healing which might be more reflective of VLU chronicity. It is also known that VLUs have a long healing process and a cross-sectional approach may only be able to provide a snapshot of the lengthy process. A longitudinal design monitoring the healing process for longer would provide more insight as to the impact of the periwound condition in wound healing outcomes.

Visual assessment data for this study was gathered from a cohort of experienced clinicians, but the clinician who assessed study participants varied during the study. All clinicians had specialist training in wound management or were undertaking a course in wound management. Although this particular clinic fostered a practice of consulting other clinicians regarding wound assessment, the possibility of inconsistency between multiple observers in this study is acknowledged as potentially impacting the validity and reliability of visual assessment data.

Finally, it is also recognised that this study is limited by a small sample size. As such, the study may have had insufficient power, which increased the potential of making Type II errors. Having insufficient statistical power might have limited the chance of detecting a true effect and also weakens conclusion validity as only a small sample was assessed.

The need for clinicians to assess VLU periwound as part of optimising management and treatment has been documented for more than a decade. Surprisingly, little has been done to explore whether periwound conditions such as maceration, dehydration and erythema are related to VLU chronicity. To the researchers' knowledge, this study addressed these gaps by examining associations between periwound status as assessed visually and using

an objective skin diagnostic device and VLU chronicity. Although this study was unable to find significant associations between wound characteristics and the periwound status of VLUs, this study provides preliminary insight into associations between periwound hydration and erythema and VLU chronicity. Modifying the study design to enable longitudinal follow up and the recruitment of a larger sample might deepen the understanding about associations between VLU chronicity and periwound status.

Overall, a paucity of studies investigating VLU periwound status and the implications on VLU healing and chronicity is noted. This study has contributed to knowledge regarding periwound status and VLU chronicity by finding that clinician assessment of periwound hydration is strongly associated with an objective method of assessment using the SD202. This study also found some associations between VLU periwound chronicity and periwound status that should be explored in further studies. Future research should build on these study findings to clarify how periwound status can be assessed in a valid and reliable manner, and how periwound assessments can be used to improve VLU management and treatment.

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