What is the “normal” wound bed temperature? A scoping review and new hypothesis

Georgina Gethin PhD, MSc, Clinical Research, PG Dip Wound Healing, FFNM RCSI, Dip Anatomy, Dip Applied Physiology, RGN1,2,3 | John D. Ivory MSc, PhD Candidate1,2,4 | Duygu Sezgin PhD, RGN1,2 | Hendrik Muller MSc, PhD Candidate2,5 | Gerard O’Connor PhD2,5 | Akke Vellinga PhD2,6

1School of Nursing and Midwifery, NUI Galway, Galway, Ireland
2Alliance for Research and Innovation in Wounds, NUI Galway, Galway, Ireland
3School of Nursing and Midwifery, Monash University, Melbourne, Victoria, Australia
4Irish Research Council (IRC), Dublin, Ireland
5School of Physics, NUI Galway, Galway, Ireland
6School of Medicine, NUI Galway, Galway, Ireland

Correspondence
Georgina Gethin, School of Nursing and Midwifery, NUI Galway, Galway, Ireland.
Email: georgina.gethin@nuigalway.ie

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Abstract
Wound bed temperature measurement holds the potential to be a safe, easy to use, and low-cost tool to aid objective wound bed assessment, clinical decision making and improved patient outcomes. However, there is no consensus on the normal range of wound bed temperature in chronic wounds. We conducted a scoping review including any study type, from 2010 to 2020 in which chronic wound bed temperature was reported. Thirteen studies including 477 patients met our criteria. Venous ulcers (VLU) accounted for 46.5% (n = 222) of wounds; diabetic foot ulcers (DFU) for 25.4% (n = 121) with pressure ulcers (PU), mixed arterial venous ulcers (MAVLU) and unknown aetiology accounting for the remainder. The weighted mean of means for wound bed temperature was 31.7°C (n = 395) for all wound types; 31.7°C for VLU; 31.6°C for DFU; 33.3°C for PU; 30.9°C for MAVLU; and 32.0°C for those with unknown aetiology. Based on our review, we hypothesise that normal wound bed temperature is within a range of 30.2–33.0°C.

1 | INTRODUCTION

The worldwide prevalence of wounds is increasing, with current estimates of 2.2 (CI 0.6–4.9) per 1000 population for all wound aetiologies.1,2 So too, are associated costs,2 estimated to account for up to 4% of total health care expenditure in developed countries.2 Chronic wounds such as venous, arterial, pressure and diabetic foot ulcers have high levels of morbidity and impact negatively on the individual, society and the health system.2

Central to the development of a treatment plan is comprehensive assessment of the individual and their wound. However, current approaches to wound bed assessment are largely subjective and depend on the skill and expertise of the clinician.3 Current literature reflects an increasing interest in the use of wound temperature as a means of enhanced and objective wound bed assessment.3–5

Physically, temperature is a measure of the motion of atoms and molecules; this internal thermal energy is distributed across translational, vibrational and rotational excitations. Warm blood from the body-core, and with it the thermal energy, is pumped into finer blood vessels in the skin. From small vessels, thermal energy can distribute through the skin by collisions with neighbouring molecules and finally to ambient air and away from the body by convective flow optionally absorbed as latent heat in vapor.6 Variations in blood flow by tissue damage or inflammation, together with vaporisation of wound-fluid can influence wound-temperature. Some equilibrated internal vibrational energy is emitted as electromagnetic infrared radiation, which contributes to heat-transfer and can be detected by infrared cameras to

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measure wound temperature. Normal core body temperature in humans is usually within a range of 36.5–37.5°C. Skin temperature on the trunk varies between 33.5–36.9°C, but is lower around areas such as the nose and in distal areas such as the feet.

The instrumentation to measure wound temperature is relatively simple and infrared cameras can easily determine the temperature of a wound. However, several questions remain: what is the normal range of wound temperature, what do temperatures above or below this range tell us, and can this knowledge guide clinical decision making?

2 | OBJECTIVES

1. To map wound bed temperatures as reported within the literature and determine a mean temperature according to wound aetiology.
2. To propose a hypothesis for a normal range of wound bed temperature.

3 | METHODS

3.1 | Design

A scoping review was used to identify a broad range of literature reporting wound temperatures for chronic wounds. The Preferred Reporting Items for Systematic Review and Meta-Analyses extension for scoping reviews (PRISMA-ScR) guidelines were employed for this work.

3.2 | Search strategy and information sources

A search strategy limited between 01 January 2010 and 24 April 2020 was developed in Medline (Appendix I), adapted for use in Embase, CINAHL, Central, Scopus and Web of Science, and run between 22 and 24 April 2020.

3.3 | Eligibility criteria

(1) Adult patients with current, open chronic wounds (venous leg (VLU), diabetic (DFU), mixed arterio-venous leg ulcers (MAVLU) or pressure ulcers (PU)); (2) any study design providing wound bed temperature data; (3) conducted in any care setting; and (4) published in any language. Exclusion criteria were: healed wounds, peri-wound area temperatures, nonulcerated patients (e.g., diabetic neuropathy but no ulceration), surgical or acute wounds, malignant fungating wounds, burns, and wounds secondary to conditions such as pyoderma gangrenosum or sickle cell anaemia.

3.4 | Selection of evidence

Search results were imported into a web application (rayyan.qcri.org) and deduplicated. The screening process was pilot tested and all titles and abstracts were independently screened by single reviewers (GG, DS and JDI). In cases of uncertainty, decisions were made by consensus following discussions between reviewers.

3.5 | Data charting process and data items

A pre-designed and piloted data extraction form was used to include: patient demographics (age and gender), wound data (aetiology, size and infection status) and wound bed temperature. Data was extracted by one author (GG) and verified by two other authors (DS and JDI).

Mean wound bed temperature was recorded as the main outcome and a mean of means was weighted for sample size. Weighted mean temperatures were compared using ANOVA (IBM SPSS v26.0) and a backwards elimination to identify significant differences was applied. Significance was set at $p < 0.05$.

4 | RESULTS

4.1 | Search results

Database searching identified 5947 records. After de-duplication, 4414 titles and abstracts were screened for eligibility. Of these, 59 went through full text screening. Forty-six full texts failed eligibility criteria (Appendix II).

4.2 | Study characteristics

Thirteen studies met eligibility criteria (Table 1).

4.3 | Patient characteristics

Thirteen studies representing 477 patients were included. Gender distribution was reported in seven, and 206 (58%) participants were female. Age was reported as a mean, and/or range, spanning from 21 to 80 years across all studies.

4.4 | Wound characteristics

Of the 477 patients, 222 (46.5%) had VLU, 121 (25.4%) had DFU, eight (1.7%) had PU, 36 (7.7%) had MAVLU and 90 (18.9%) had ulcers of unknown aetiology. No wounds were reported as infected.

Mean wound size weighted by number of patients was: 16.6 cm$^2$ for all wounds; 20.9 cm$^2$ (n = 204 patients/two studies); 4.1 cm$^2$ (n = 78 patients/2 studies); 54 cm$^2$ (eight patients/one study); 0.9 cm$^2$ (16 patients/one study); and for ulcers of unknown aetiology, 20.3 cm$^2$ (12 patients/one study).
4.5 | Wound bed temperature

Temperature ranges were reported for 176 patients in seven studies.\textsuperscript{4,16,17,19–21,24} This ranged from 25.1°C to 35.3°C. Mean baseline wound bed temperature was reported in 11 studies.\textsuperscript{3,8,15–20,22–24} Only one study\textsuperscript{21} reported a median (range) wound bed temperature of 30.9°C (29.3°C–35.3°C) in 20 MAVLU patients.

The weighted mean of means for wound bed temperature for all aetiologies was 31.7°C ± 1.4 (n = 395 patients). For each aetiology specifically: VLU, 31.6°C (n = 204/two studies)\textsuperscript{15,16}; DFU, 31.6°C (n = 77/four studies)\textsuperscript{12–14,15}; PU, 33.3°C (n = 8/one study)\textsuperscript{20}; MAVLU, 30.9°C (n = 16/one study)\textsuperscript{3}; unknown aetiology, 32.0°C (n = 90/four studies)\textsuperscript{8,22–24} (Table 2). When compared, the weighted mean of means of the wound bed temperature of PU and patients with unknown aetiology ulcers were significantly higher compared to VLU, DFU and MAVLU (Figure 1).

Only eight patients had pressure ulcers and of these, three had grade two; three had grade three and two had grade four.\textsuperscript{20} Results were not reported according to stage. We speculated that these wounds were different in their aetiology, depth and anatomical location, and therefore, we repeated data analysis after excluding them. In addition, those of unknown aetiology included trauma wounds and chronic wounds without stratification of results based on aetiology and we excluded these from a secondary analysis.

5 | DISCUSSION

The premise that tissue heats up before it breaks down is an important one.\textsuperscript{25} If we can identify the temperature above which a wound is “too hot” we have an objective measure which will allow us to intervene at an earlier stage and prevent deterioration. In a chronic wound, increased local temperature is one of the classic signs of wound infection and inflammation, and its quantitative measurement may be useful to optimise the assessment and treatment of lesions.\textsuperscript{4}

Our review provides data to show that the overall weighted mean of means temperature of the wound bed was 31.7°C (±1.4). Depth of tissues was a consideration in understanding reported temperature. The mean temperature was 33.3°C in PU, which may suggest that deeper wounds have temperatures being closer to core body temperature. In addition, all PUs in this study were on the sacrum, an area of good tissue perfusion. Similarly, wounds of mixed arterio-venous aetiology had slightly lower temperatures of 30.9°C which may be reflective of poorer blood supply and consequent poorer warming of the wound bed tissue. Considering the small sample size and these differences in aetiology of PU and other (unknown) aetiologies, which may explain the significant difference, we report both including and excluding these from our estimates.

The majority of wounds (VLU, DFU and MAVLU [total 80%]) resulted in a weighted mean of means at 31.6°C (±1.4) Based on our
review we are hypothesizing that the wound bed temperature of chronic, non-infected wounds would be within one standard deviation of the weighted mean of means of 31.6°C ranging from 30.2°C to 33.0°C.

Studies have shown that 33°C is the critical level at which neutrophil, fibroblasts and epithelial cell activity decreases in an in vitro setting. In addition, when wound bed temperature falls below core body temperature, it is proposed that healing is delayed due to lack of collagen deposition and a reduction in last-phase inflammatory cells and fibroblasts. Based on the real-life studies presented in this review, we suspect the 33°C critical level based on in vitro studies does not correspond with the actual reported temperatures. A previously proposed alternative threshold of 28–32°C is further supported by this review with further refinement to 30.2–33.0°C, but caution remains in interpreting this and further studies to validate this are required.

This hypothesis should be tested in large cohorts of patients across various wound aetiologies with follow up to healing and infection outcomes. The ultimate test of clinical utility should be randomised controlled trials to determine the impact on clinical decision making and patient outcomes. Such a rigorous approach will ensure we are not wasting resources on developing devices without the evidence that temperature can support and improve outcomes.

6 | LIMITATIONS

The studies included in our review used a wide variety of apparatus to measure wound temperatures. The intent of our scoping review methodology was to present a general estimate of the normal range of chronic wound temperatures. An in-depth analysis of extracted temperature data that took measurement error and variation in apparatus into account was beyond the scope of this work. Further studies should take this into consideration.

Studies not specifically reporting wound bed temperature as a secondary outcome in their title or abstract means that we may have missed eligible data in our search. We would welcome inclusion of such data in the future to update our database.

7 | CONCLUSION

Based on our review, we hypothesise that wound bed temperature falls within a “normal” range of 30.2–33.0°C. Validation of such a reference range, in particular if this interval can be narrowed through adding more and larger studies, has the potential to support and improve clinical decision-making.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Georgina Gethin https://orcid.org/0000-0001-5859-8357
John D. Ivory https://orcid.org/0000-0002-8445-4602

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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