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# Monitoring wound healing in minor burns—A novel approach

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ABSTRACT

Assessment of minor burn wound closure is predominately determined by visual inspection and clinical specialist assessment, which remains largely a subjective analysis and results may vary depending on the clinician's experience. Bioimpedance spectroscopy (BIS) is an instrument that has a demonstrated ability to objectively monitor the wound healing process in various patient populations but has not yet been used in acute burn wounds.

The aim of the pilot study was to examine whether the BIS technique is a valid measure of wound healing.

Localised BIS resistance and phase angle triplicate measures, of minor limb burns, were collected on two serial occasions. Circumference limb measures were taken at the localised burn site to determine a truncated limb volume. Proportional-odds ordered logistic regression analyses determined resistance at zero frequency ($R_0$, indicative of edema) and resistance of total body fluid ($R_{inf}$) were significantly associated with healing after adjustment for the influence of surgery. A one unit increase in $R_0$ and $R_{inf}$ increased the odds of wound healing by 6% and 5% respectively ($p<0.01$). Phase angle at 50 kHz and $R_i$ were not significantly associated with the markers of the wound healing process. Spearman's correlation determined there was a significant association between a healing wound and limb segment volume (ml) (rho −0.30, $p<0.01$). BIS is a technique, which has the potential to monitor the progress of wound healing.



## 1. Introduction

Wound healing, re-epithelisation, is a complex but well described physiological process. Erythema, heat, pain and swelling are classic symptoms of both acute and chronic wounds, which are caused by a vascular and cellular inflammatory response of the body to injury [1]. Timely treatment of the wound and associated symptoms is crucial for providing the best possible environment for healing. Acute burn wounds are unique in their degree of swelling. After a

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burn the body responds with an influx of chemical and inflammatory mediators resulting in excess swelling [2].

Immediate management of a burn wound should include optimum first aid, management of swelling and medical attention with appropriate dressings [3,4]. Improvements in dressings, surgical intervention and the advent of antibiotics over the decades has improved aspects of burn wound care, yet edema remains an issue. It is known that in the first 3–5 days after burn when assessed according to Jackson's three zones of tissue injury [5], the burn wound can progress, thus increasing the wound depth and time to healing and increasing the risk of a worse scar and functional outcome [6]. Time to healing is directly related to severity of scarring [2].

Edema is considered a primary impediment to the healing process and burn wound conversion [7]. The specific mechanism by which edema interferes with healing is unknown but is theorised to be related to compromised vascular and tissue diffusion dynamics [8]. Peri-wound edema is thought to impair the clearance of cellular debris and waste; to prevent the migration of inflammatory cells impairing defence from infection and antigens; and impeding nutrient transport from the capillary bed to the cell [9]. Other factors affecting healing are an individual's pre-morbid health and age. Systemic factors such as diabetes, peripheral vascular disease and obesity are associated with slowed wound healing [10].

It is essential to monitor wound healing closely to ensure the most appropriate intervention to promote healing is carried out. In clinical practice the assessment of a burn wound must include the wound size (total body surface area (TBSA)), depth, agent and days after burn. Each of these factors helps guide the best and optimal medical management of the patient [11]. Other signs such as wound edema volume and chemical changes in the wound surface are essential assessment points and may indicate infection [1].

The most common measures used to assess a burn wound are: visual evaluation; photos, TBSA and depth (determined by color, skin elasticity, hairs left) [12,13]. These are influenced by a certain degree of subjectivity and clinician specialisation and training. Clinician assessment of a burn wound has been shown to be accurate only 60–75% of the time [14]. The use of computer software, planimetry, wound biopsy, laser Doppler and ultrasound can be used to objectively assess the structure of the wound but these can be expensive, require specialist training and do not necessarily provide immediate results [15]. In the burns wound environment, dressings may remain in place for 2–5 days, limiting wound assessment unless dressings are removed. Having the capability to monitor wound healing with a dressing in place would limit dressing cost, decrease patient burden and pain and potentially detect infection and delayed or poor healing in wounds earlier. Kenworthy et al. (the authors of this study) found bioimpedance raw resistance measures, can monitor localised changes in acute burn edema with dressings in place [16]. In addition, the ability to monitor wound healing in real time, non-invasively and without subjectivity would be advantageous and minimise error.

Bioimpedance spectroscopy (BIS) is an instrument with this potential. It can measure the body's inter-compartmental fluid volumes, indicate metabolic state and cell health through passing a small electrical current, over a number of frequencies, via electrodes placed on the skin and measuring the voltage drop between them [17]. The current flows depending on the body's composition. The body offers two types of resistance to an electrical current. They are resistive R (resistance) and capacitive R (reactance) [18]. Resistance is the opposition to flow of an electric current and capacitance is the delay in the passage of current through the cell membranes and tissue interfaces. The BIS instrument measures real time raw variables (resistance (R), reactance (Xc) and phase angle (PA)) using current frequencies of 4–1000 kHz. Mathematical formulas embedded in the BIS instrument then utilise these raw variables to estimate the inter-compartmental fluid volumes [19].

Resistance has an inverse relationship to fluid volume due to alterations in electrolyte concentration, so as the fluid volume increases R decreases. Resistance at zero ($R_0$) frequency theoretically indicates extracellular fluid ((ECF) edema), as the current does not traverse the cell membrane. Higher frequency currents pass through the cell membrane and ionic extracellular environment, therefore R at infinity frequency ($R_{inf}$) indicates total body fluid (TBF) [20]. Practical limitations prevent the use of zero frequency (direct currents) and low high frequency alternating currents, therefore values of $R_0$ and $R_{inf}$ are predicted by the BIS instrument using a Cole–Cole plot [21]. Resistance of the intracellular fluid (ICF) ($R_i$) is extrapolated using the other raw variable data. Reactance represents cell membrane mass and function. Phase angle, calculated as the arc tangent of Xc/R and expressed in degrees [18]. The capacitance of the cell membrane causes the current to lag behind the voltage as it traverses the cell, creating a phase shift of the waveform as measured by BIS [22]. If the health of the tissue is disturbed in any way (e.g. inflammation, disease) the electrical properties of those tissues (cell membranes) are altered. Phase angle is therefore promoted as a measure of cell membrane health and a prognostic indicator of malnutrition and disease [23]. As the health of the cell improves, the transit of the BIS current and voltage is delayed, thus resulting in greater PA's. In experimental case studies, BIS R and PA measures have been, shown to be associated with wound healing in acute and chronic wounds [24–26]. Resistance measures were also positively associated with histological measures of healing in surgically induced wounds in rats [26]. The following study therefore aims to examine whether the BIS technique is a valid measure of wound healing. Based on the evidence from the literature it is hypothesised R and PA will increase with burn wound healing.

## 2. Methods

### 2.1. Participants

Participants were recruited from the Western Australian State Burns Service, outpatient clinic between December 2014 and December 2016.

Participants, who were over 18 years of age, had a minor limb burn (less than five percent TBSA) which was less than four days old were eligible for inclusion in the study.