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A prospective pilot study of the energy balance profiles in acute non-severe burn patients

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Abstract

Background: Major burn patients have been shown to exhibit a hyper-metabolic state of activity which can persist for up to two years after burn. The relationship between total body surface area (TBSA) and resting metabolic rate (RMR) has been investigated in larger burns (>20% TBSA), however not in non-severe burns (<15% TBSA). The primary aim of this observational study was to examine the association between the acute effects of burns <15% TBSA with RMR in patients using indirect calorimetry, as well as any potential covariates. The secondary aim was to determine 24-h energy balance.

Methods: The study included data from 39 participants (82% male), all admitted to the State Adult Burn Unit at Fiona Stanley Hospital. Each patient was recruited upon admission and RMR data was collected on day four (+ or - one day) after burn. Results: The pooled data bivariate correlation showed a significant relationship between RMR and TBSA (r=0.435, p=0.009). A stronger relationship was also found between RMR and TBSA in males (r=0.634, p=0.001). Patients recorded a caloric deficit of 116 kcal/day.

Conclusion: This study demonstrated that a moderately strong linear association exists between RMR and TBSA in males for burns of <15% TBSA. The energy balance data indicated that supplementation of caloric intake for non-severe burns suggests careful consideration.

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1. Introduction

Burns are a complex injury caused by exposure to heat, chemicals, electricity or sunlight that affects the skin and deeper associated tissue [1]. The physiological response to a burn injury occurs across two phases that represent a shift in metabolic activity. The first phase is referred to as the ‘ebb’ phase, occurs within 48h of the initial injury, and is characterized by decreased circulation (cardiac output and oxygen consumption) and subsequently resting metabolic rate (RMR) [2]. This is referred to as a hypo-metabolic response. These physiological responses have been observed in major burn patients, and gradually increase over the first 4–5 days after injury before achieving a plateau in a hyper-metabolic state, referred to as the ‘flow’ phase [2].

The research into the interaction between surgery and energy expenditure after non-severe burn is an area that is lacking, despite Miller et al. (2006) reporting that as many as 62% of burns effect <10% total body surface area (TBSA) [3]. There is conflicting findings regarding the metabolic response to surgery, with some research [Williams et al., 2009; Hart et al., 2003] suggesting an apparent reduction due to early excision (<72h of after burn) compared to later excision at one (1) week after injury [4,5]. While others (Hart et al., 2003) have shown time of excision did not alter the hypermetabolic response to a burn [6]. These conflicting findings suggest that more investigation is necessary to determine the metabolic response to surgery in burned patients. Further, this work has been carried out in larger burns and is yet to be comprehensively investigated in non-severe burns.

Nutritional supplementation is a key component of treatment for burned patients, as with changing metabolic activity, nutritional utilisation of the body also change [7]. The objective of nutritional support is to minimize preferential seeking of lean body mass as a fuel source during the acute phase after burn by matching the caloric estimates of the patient, as determined by their RMR [7]. Conversely clinicians aim to avoid overfeeding burned patients which can lead to increases in fat deposits in key organs and adverse events after burn. As such a neutral balance of intake to expenditure is desired by clinicians [7]. Matching the caloric intake to the energy consumed by the body daily is referred to as energy balance, maintaining this is crucial to minimize further loss of muscle mass during the burned patients hospital stay [7–9]. A caloric deficit indicates that the estimated daily metabolic expenditure is greater than the caloric intake available to the patient.

The effect of moderating variables on resting metabolic rate is not well understood in non-severe burns [10]. While not an exhaustive list, moderating variables include age, sex, body mass index (BMI), body temperature, strength and heart rate. Evidence suggests these variables have a level of association with RMR, though it is acknowledged this was demonstrated in healthy populations [10]. Johnstone et al. (2005) investigated the association of age and body composition with RMR in a healthy adult population, and found fat free mass explained 63% of variation. Some of this variation was explained by fat mass and age, however it was also stated that morphological characteristics alone cannot explain the between-individual characteristics in RMR, and physiological effects must also be examined [10].

The majority of research pertaining to burns and their effects on metabolism has been conducted in large burns (>20%) with relationships for non-severe burns extrapolated from trends seen in these larger burns [11]. As such there exists a lack of surety in the literature regarding the metabolic expenditure relationships in non-severe burns, despite the vast majority of burns falling into this category [12]. Therefore, this study aimed to (1) investigate the association of RMR with TBSA for non-severe burns at day four (± one day) after burn, along with any potential covariates, and (2) examine the 24-h energy balance of burned patients.

2. Materials and methods

2.1. Design

This observational study employed a prospective cohort design. All participants were measured for RMR on the fourth day after burn (± one day) as the primary measure of the study, regardless of whether they had surgery prior to baseline testing. Secondary measures of caloric intake and moderating variables were recorded in tandem. The tolerance of one-day around the measures provisioned the dynamic of the acute hospital environment and rapidly changing surgical scheduling. The day of injury was designated as day zero, regardless of the date of admission to the burn unit. This time frame was selected due to the metabolic plateau theoretically occurring approximately four (4) days after burn, signifying the ceiling of the hyper-metabolic state [2].

2.2. Participants

Recruitment took place over a five-month period (May – September 2019). Patients were recruited as soon as possible after admission, which ranged from one to seven days after burn. The inclusion criteria were; patients >18 years, presenting to the inpatient ward of the burns ward with burns <15% TBSA. Exclusion criteria included; mechanically ventilated patients, burns to the mouth that would limit the ability to form a seal around the mouthpiece for RMR testing, and electrical and inhalation injury due to the difficulty in determining TBSA burnt in these types of injuries. This study and its methods were approved by both the relevant institutional human research ethics committees.

2.3. Outcome measures

2.3.1. Physiological measures

Metabolic data, as indicators of RMR, were collected via indirect calorimetry to calculate metabolic rate and substrate oxidation via measurement of gas exchange at rest (Quark RMR, COSMED, Italy) [9]. Standardised procedures for the collection of RMR were adhered to, based upon Compher et al. guidelines [13]. Expired gas was collected from the COSMED device for the calculation of predicted REE. Predicted REE was determined by the Harris Benedict equation, with calculations for fat and carbohydrate oxidation utilizing VO2 and VCO2 data.
All tests were completed between 6.00 and 8.00 am in a fasted state and occurred prior to any wound dressing or other pain inducing procedures, room temperature is standardised on the ward and controlled to 24–26°C.

Gas exchange was collected for five (5) minutes after a steady state had been achieved. RMR was calculated from the gas exchange data via the use of the modified Weir formula [14].

\[
24 \text{– hour resting energy expenditure} = 1.44 \left( \frac{3.94 \times \text{VO}_2}{1.11 \times \text{VCO}_2} \right) + 10.5 \quad \text{kJ/day/kg}
\]

Volume of oxygen, \(\text{VCO}_2\) = Volume of carbon dioxide

Body temperature and heart rate were collected prior to baseline (day four) RMR testing as both can exhibit changes throughout recovery after burn. Both measures were taken from observation charts completed by nursing staff, taken immediately prior to RMR testing.

2.3.2. Nutritional measures
Dietary intake was recorded via standard hospital dietary intake form, as well as the researcher recorded percentage of the meal consumed to determine caloric intake over a 24-h period before RMR testing. This included any protein supplements the patients may have been prescribed. The dietary information was interpreted as the assumed number of calories consumed according to the Foodworks dietary analysis program (Version 10; Xyris, Australia).

2.4. Covariate measures

2.4.1. Appetite measure
Each patient’s appetite was recorded after lunch by the researcher the day before RMR testing (as per caloric intake) using appetite-specific visual analogue scales. These scales asked patients to separately rate their sensations of hunger, fullness, desire to eat and quantity the patient could eat.

2.4.2. Anthropometric measures
Descriptive data including age, sex, height and weight were collected at baseline with body mass reported from hospital observation charts on the day of each testing session (Table 1). Burn size was recorded as TBSA, assessed upon admission by the nursing staff and again during surgery by the attending surgeon using a combination of the Rule of Nines and the Rule of Palms methods [15].

2.4.3. Grip strength
An analogue handheld dynamometer (Sammons Preston Rolyan, Bolingbrook, Illinois, USA) was used to assess grip strength. Patients were seated on the side of their bed, with their elbow flexed at 90° [16]. Using their dominant hand first, the patient closed their grip on the handle as hard as possible for three (3) seconds to register their best possible isometric strength outcome, this was then repeated on the non-dominant hand. This procedure was repeated three times with the highest strength value from each hand recorded for analysis. This measure was included as it has been validated as a quasi-measure of strength in various clinical populations and correlates well with other measures of overall body strength. Grip strength has also been identified as an indicator of functional ability due to its association with arm, back and leg strength [17]. This measure was also assessed as a potential co-variate to determine if strength plays a role in variation in energy expenditure in non-severe burned patients.

2.4.4. Physical activity
To determine each patient’s recent physical activity history, the International Physical Activity Questionnaire (IPAQ) short form was used to quantify physical activity levels in the last seven (7) days before being admitted to hospital [18]. The data from this questionnaire represented a MET score for each patient and was assessed as a moderating variable for RMR.

2.5. Statistical analysis
Data collected was analysed using Statistical Package for the Social Sciences Statistics (version 26; IBM corp., Somers, NY, USA), significance was set at \(p \leq 0.05\). Data is presented as a combined group and by sex to account for lean muscle mass differences between males and females, however due to a lack sample size in the female sub-group analysis was not possible [19,20].

Pearson’s product moment correlations were used to examine the relationship between TBSA and RMR, as well as any existing relationship between substrate oxidation (fats and carbohydrates) and between TBSA, appetite and energy intake. Energy balance was determined as the difference between calories consumed in the 24h prior to RMR collection and the calories utilised. For the covariate measures of potential moderating variables, a forward stepwise linear regression was used to determine any effects of age, sex, BMI, grip strength, caloric intake, appetite scores, body

| Table 1 – Descriptive characteristics for all 45 recruited participants. |
|-----------------------------|-----------------------------|-----------------------------|
|                             | Combined (n=45)              | Male (n=35)                 | Female (n=10)               |
| Age (years)                 | 43.0 ± 2.0 (19–85)           | 42.1 ± 1.8 (19–85)          | 46.0 ± 2.4 (19–84)          |
| TBSA (%)                    | 3.7 ± 3.3 (0.2–15.0)         | 3.2 ± 2.7 (0.2–11.0)        | 5.2 ± 4.7 (1–15.0)          |
| Height (m)                  | 1.73 ± 0.11 (1.52–1.95)      | 1.78 ± 0.07 (1.65–1.95)     | 1.59 ± 0.05 (1.52–1.65)     |
| Weight (kg)                 | 79.0 ± 19.2 (54–133)         | 89.2 ± 17.7 (56–133)        | 64.4 ± 9.2 (54–83)          |
| BMI                         | 24.0 ± 5.2 (18.9–42.9)       | 28.2 ± 5.4 (18.9–42.9)      | 25.6 ± 4.7 (19.8–34.4)      |
| Physical Activity (IPAQ – MET-min/week) | 3519 (660–9495) | 6852 (1572–12105) | 561 (82–1372) |
| Heart rate (bpm)            | 68 ± 11 (50–90)              | 67 ± 12 (50–90)             | 71 ± 9 (60–80)              |
| Body temperature (°C)       | 36.5 ± 0.2 (36.2–36.9)       | 36.5 ± 0.2 (36.2–36.8)      | 36.6 ± 0.2 (36.3–36.9)      |

Data presented as Mean ± Standard deviation (range), IPAQ data presented as Median (IQR).
temperature, heart rate and exercise history on variation in RMR. Descriptive statistics were preferentially presented as Mean and Standard Deviation, or where data were skewed, median and interquartile range was used. An independent t-test was used to examine the differences between the male and female IPAQ scores.

2.6. Ethics

Patients provided informed consent prior to participation in the study. The study was approved by South Metropolitan Health Service Human Research Ethics Committee (RGS0000000013) and Murdoch University Human Research Ethics Committee (2016/228).

3. Results

3.1. Participant characteristics

A total of 112 patients were screened for eligibility, with 45 patients (35 male, 10 female) recruited to the study (Fig. 1). After recruitment to the study, 6 patients were excluded as data were not able to be collected (3 patients were transferred to another ward before testing, and three (3) chose to withdraw on the morning of testing), resulting in 39 patients (32 male, 7 female) participating in the study. Descriptive characteristics for all recruited patients are presented in Table 1.

3.2. Association of TBSA with RMR

Mean RMR for participants was 2157 kcal day⁻¹. The bivariate correlation between TBSA and RMR was shown to be positive, with a significant yet moderate positive relationship (r=0.435, p=0.009, n=35) (Fig. 2). Four (4) patients who had data collected were not within ±1-day window of day four (4) data collection, and thus their data was excluded from analysis. In a subsequent sub-group analysis, male RMR was 2360 kcal day⁻¹. The bivariate correlation was indicative of a significant moderate-strong positive relationship with TBSA of r=0.634, p=0.001 (Fig. 3).

3.3. Energy balance of burned patients

The difference between energy intake and expenditure for males and females combined was a non-significant caloric deficit of 116 kcal day⁻¹ (p=0.23) (range -1188 to +1757 kcal day⁻¹). Male burned patients reported -257.31 kcal day⁻¹ difference in energy balance (p=0.11) (Fig. 4). Twenty-six (26) patients had the dietary recall completed and were included in this analysis.

3.4. Associations of moderating variables on variations in RMR

Height was found to be the most influential moderator (r=0.481) of RMR for the combined group. The strongest moderating variable for the male sub-group was age (r=0.614) (Table 2).

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**Fig. 2** – Baseline Resting Metabolic Rate (RMR) and Total Body Surface Area (TBSA) correlations for combined 35 participants.

**Fig. 3** – Baseline Resting Metabolic Rate (RMR) and Total Body Surface Area (TBSA) correlations for subgroup of male only participants.

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3.5. Measured RMR and predicted RMR comparison

The measured RMR was compared to age predicted RMR to determine any differences above what is expected. Average measured RMR for the combined males and females was 151% of age predicted RMR (male 158%; female 132%).

3.6. Appetite, intake and TBSA relationships

There was no significant relationship evident between reported appetite and TBSA for the combined male and female data (r=0.142, p=0.490, n=26), or for males only (r=0.023, p=0.926, n=19). There was no relationship between energy intake and TBSA for either combined males and females (r=−0.108, p=0.569, n=30) or males only (r=−0.149, p=0.487, n=24). There was no evidence of relationships between appetite and energy intake for combined males and females (r=−0.034, p=0.876, n=24), or males only (r=−0.114, p=0.656, n=18).

3.7. Effects of burn size and RMR on substrate oxidation

Substrate oxidation was analysed for fat and carbohydrate utilisation. Fat oxidation was recorded at 736 kcal/day⁻¹ and carbohydrate oxidation 1367 kcal/day⁻¹. In males only there was an average of 674 kcal/day⁻¹ of fat and 1594 kcal/day⁻¹ of carbohydrates utilised.

There was no evidence of an association between TBSA and fat (r=0.08, p=0.682, n=26) or carbohydrate oxidation (r=0.03, p=0.884, n=26). Similarly, there was no evidence of a relationship between RMR and fat oxidation (r=−0.08, p=0.714, n=26). In contrast, RMR and carbohydrate oxidation demonstrated a moderate-strong correlation (r=0.70, p=0.001, n=26).

There was no evidence of a relationship between TBSA and fat (r=−0.0004, p=0.987, n=19) or carbohydrate oxidation (r=0.44, p=0.068, n=19) in males. In this male subgroup, there was no evidence of a relationship between RMR and fat oxidation (r=0.03, p=0.911, n=19), however, RMR and carbohydrate oxidation showed a moderate-strong correlation (r=0.6206, p=0.013, n=19).

4. Discussion

The novel findings from this study were: 1) a linear relationship exists between TBSA and resting energy expenditure for males with non-severe burns, concurring with findings in larger burns (≥20%) [2,11,12,21] (Fig. 3); 2) Caloric intake was 116 kcal/day less than expended energy in burned patients, suggestive of a ‘conservative’ feeding strategy previously reported in this population, seeing patients fed less calories than they are expending [7]; 3) Moderating variables showed minimal influence on observable variations in RMR; and, 4) there is a moderate-strong correlation between carbohydrate oxidation and RMR in non-severe burned patients. Data for female participants within this study was limited heavily due to a reduced sample size compared to the male cohort, though this pattern of recruitment is in keeping with previous research that suggests that males are twice as likely to suffer a burn injury [22].

Previous research in larger burns has reported REE is often 120–140% of non-burn predicted RMR [2,4,11,12,21]. Interestingly we are the first to report that this association is also present in non-severe burned patients. Given the association we have found in this study between REE and TBSA in smaller burn injuries being similar to what has been reported in larger burns, it is plausible that there may be a difference between measured and predicted REE in smaller burns. We believe this may be attributed to similar metabolic response being observed in smaller burns patients compared to larger burns. Of important note for these observed changes the ambient room temperature for these participants was standardised between 24 and 26 °C, and the Harris Benedict equation being used to estimate age predicted REE.

The combined sex cohort were assessed to have a measured RMR at 151% of non-burn predicted RMR, with males 158% of non-burn predicted RMR. This hyper-dynamic response is associated with increased body temperature, increased oxygen and glucose consumption, and excessive substrate usage [2,11]. Our study demonstrated a moderate-strong correlation between TBSA and RMR (r=0.63, p=0.001) in male burned patients (seen in Fig. 3). Larger burns result in a greater rate of energy expenditure in the acute stages of recovery, however this positive linear trend has previously only been assumed in non-severe burns. It is plausible this would occur in smaller burns, with similar pro and anti-inflammatory responses being observed in non-severe burned patients (≤20% TBSA).
compared to larger burns across the 4 weeks following a burn injury [23,24]. We have demonstrated this trend does in fact occur in males with non-severe burns. This was expected to be the case for non-severe burns (<15%) due to the systemic nature of the hypermetabolic response to burn injuries [2,21]. However, to the authors’ knowledge, no other study to date has reported this finding.

There was a moderately strong relationship between TBSA and RMR (r=0.435, p=0.009) (Fig. 2). Sex differences for RMR have not been investigated in non-severe burns and the lack of female participants in this study did not allow us to investigate this validity. By analysing RMR and TBSA relationship in males only we were able to provide a clearer understanding of the interactions between TBSA and RMR in non-severe burns. That said, the ratio of males to females in this study is in keeping with the usual ward census (32 males and seven females) that suggests females make up 24% of all burns cases in Western Australia [25].

In keeping with previous research in healthy populations, which confirmed changes in RMR were predominantly associated with increased lean mass, height and weight, our findings demonstrate height is a strong moderating variable on RMR [26]. Sex, heart rate and grip strength also showed plausible positive association with RMR variation, while age had a moderate negative effect. Non-morphological characteristics (such as heart rate) were collected and examined for their association with RMR, with only heart rate found to be a significant low association. Johnstone et al. [10] suggested an increase in heart rate as result of hyperdynamic circulation and the catabolic effects on muscular strength are common responses to a burn injury [10,19,27].

Age was the strongest association with RMR in males, which is consistent with findings in healthy controls. Physical activity (METs) and grip strength also showed a weak negative association with RMR, possibly due to the high reported physical activity levels in this study compared to research in age matched data (3519 MET-min/week vs 210 MET-min/week [33–88 years] [28]).

In order to compensate for the increased metabolic activity seen in the acute recovery phase, caloric intake should be increased to match the energy expenditure of burned patients [7]. On average, participants consumed 116kcal/day $-1$ less than their calculated energy expenditure (Fig. 4), determined via indirect calorimetry, indicative of a mean daily caloric deficit. While this difference is plausible, a larger sample size is required to confirm this, with effect size calculations showing only a small effect size (Cohen’s $d=0.23$). Male burned patients consumed $257$ kcal/day $-1$ less than their calculated energy expenditure. While this difference may be clinically meaningful; a larger sample size is required to confirm significance (Cohen’s $d=0.11$). Another interesting finding was the range seen between participants in raw energy balance data, ranging from $-1188$ kcal to $+1757$ kcal, this represents a range of $\sim 3000$ kcal between the patients, and suggests that greater emphasis may need to be placed on individualised nutritional prescription and accurate recording of intake, in burn populations to ensure that patients are receiving as close to a ‘balanced’ energy profile as possible.

A caloric deficit in burned patients can lead to additional loss of lean body mass, which is linked with increased levels of mortality [29]. Therefore, the loss of lean body mass should be avoided where possible. This finding, although non-significant, reflects the current research in larger burns that reports a conservative approach to feeding. In paediatric burns an adjustment factor of 1.4x predicted energy expenditure has been recommended to meet the energy demands of patients and maintain body weight, therefore it is likely that a similar adjustment factor is required in an adult burn population [7,30].

As the body recovers from a burn injury, the increased energy demand is reflected in an increased level of fats, proteins and carbohydrates being metabolised [7,31]. The identification of specific breakdown of fats and carbohydrates has been previously reported in large burns, using indirect calorimetry as well as other methods including 13C labelled amino acid tracers [32]. The chosen method for assessing REE in this study was indirect calorimetry, which is an established method of assessing energy expenditure in a clinical setting [13]. Carbohydrate oxidation showed a moderate-strong relationship with RMR. This was expected due to the role of carbohydrate in promoting wound healing and protein sparing during recovery from burn injury [7]. Protein oxidation was not detected in any of our results during testing, however the method utilised may not have accurately assessed protein oxidation. While not specific to non-severe burns, previous research has demonstrated amino acid oxidation rates in response to severe burn injuries. This requires further investigation in non-severely burned patients [32]. It is also plausible that the protein being supplemented is appropriate for the body to preserve stored protein, further investigation into changes in lean body mass relative to protein oxidation will clarify why protein may not be utilised at rest in non-severe burns [7].

Subgroup analysis was not feasible with females in this study, limiting factors were the time available for recruitment and the previously mentioned difficulties with patient recruitment due to the dynamic nature of the hospital environment. Future studies with larger samples and repeated measures of RMR, are encouraged.

**Conclusion**

This study confirmed a relationship between RMR and TBSA, like that which has been described in larger burns. A non-significant finding of energy deficit of 116kcal/day suggests that nutritional prescription may need to be refined in non-severe burn patients to match the increased expended levels of energy expenditure in order to optimize patient treatment.

**Conflict of interest**

The authors declare that there is no conflict of interest.

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