

Original Article

Regional tissue oxygen saturation measured by near-infrared spectroscopy to assess the depth of burn injuries

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Abstract: The burn severity depends on the wound depth and area affected. Hitherto burn depth has been judged mainly by visual observation, although concerns have been raised about its validity. The regional tissue blood flow (rTBF) measured by laser Doppler imaging (LDI) in damaged tissue correlates with the depth. However, very few reports are available on the significance of the regional tissue oxygen saturation (rSO₂) as an indicator of burn depth. We investigated whether rSO₂ by Near-infrared spectroscopy (NIRS) in burn injuries correlates with rTBF by LDI, which would facilitate quantification of the severity of the tissue damage. **Methods:** We measured rTBF and rSO₂ in 50 lesions from 14 patients of burn injury within 24 hours after injury. The correlation between rTBF and rSO₂ was evaluated by Spearman rank correlation analysis. **Results:** The rSO₂ (%; range, 52-82) by NIRS and the rTBF (perfusion unit; range, 61-704) by LDI in burn lesions were positively correlated ($r=0.755$, $p<0.001$). This statistically positive correlation still remained significant ($r=0.678$, $p<0.001$) after the rSO₂ values were standardized. **Conclusion:** This study suggests that NIRS determination of rSO₂ in burn injuries shows promise as a reliable and quick method to estimate the depth of burn lesion.

Keywords: NIRS, rSO₂, laser Doppler imaging, burn depth

Introduction

An assessment of burn depth is the initial and critical step in guiding the treatment of patients with thermal injuries. Such assessment should be objective and non-biased, but in practice continues to rely on clinical observation and visual inspection as the most practical method. However, clinical estimation of burn depth by visual and tactile assessment of the wound is often inaccurate especially in determining whether a deep burn would heal without surgical intervention, even when performed by experienced clinicians [1]. This unsatisfactory current clinical status, namely that the surgical indication regarding whether or not a burn wound requires early excision and grafting is still decided based on imprecise methods cries out for improvement. In particular, there is an urgent need for a high-resolution imaging technique that would provide quantitative information on the depth of thermal damage.

Early studies demonstrated that estimates of perfusion in the burn wound by laser Doppler imaging (LDI) strongly correlated with the burn depth and healing time [2-7]. Laser Doppler perfusion imaging has shown very high sensitivity, specificity, and accuracy in determining the burn depth when compared to histological studies. However, LDI study is still not widely used clinically.

Near-infrared spectroscopy (NIRS) has been commonly used to determine the regional tissue oxygen saturation (rSO₂) of brain tissue in patients with cerebral ischemia [8]. NIRS penetrates a broad range of tissues and utilizes reflection rather than direct transmission between an emitter and receiver pair. It is able to assess end-organ perfusion and uses a non-invasive, portable device that can be easily adapted to numerous settings including the emergency room, operating room for refinement of anesthesia, and hospital ward for bed-

Table 1. Clinical characteristics of patients with burn injury

Age	Sex	Burn Index	TBSA	Etiology	Location	Hb	SpO ₂
7	M	13	26	Scald	Leg	14.4	99% (room air)
27	M	18	35	Flame	Arm, Leg	14.8	98% (room air)
36	F	10	12	Flame	Leg	13.8	98% (room air)
40	F	18	27	Flame	Arm	14.6	96% (room air)
40	M	6	12	Flame	Arm	13.7	97% (room air)
52	F	20	23	Flame	Leg	15.3	98% (room air)
54	M	32	64	Scald	Arm, Leg	15.1	96% (room air)
61	M	52	62	Flame	Arm	14.4	99% (FiO ₂ 0.4)
62	M	6	11	Flame	Hand	15.2	98% (room air)
64	M	16	32	Flame	Hand	16.2	96% (room air)
67	F	55	72	Flame	Leg	13.1	98% (FiO ₂ 0.6)
80	F	24	36	Flame	Arm, Leg	11.6	100% (FiO ₂ 0.4)
82	M	8.5	17	Chemical	Arm	10.8	97% (room air)
89	F	7	11	Flame	Leg	15.2	96% (FiO ₂ 0.4)

TBSA, total burn surface area.

side monitoring. However, very few reports are available on the utility and feasibility of NIRS to determine the rSO₂ of burn wounds, and assess the burn depth. Since NIRS may represent a quick, easily accessible, and clinically practical method to assess burn depth, we investigated whether its usefulness is comparable to that of LDI in patients with severe burn injury.

Subjects and methods

This study was performed with permission obtained from the institutional ethics committee of Nara Medical University.

The patients recruited for the present study were admitted to Nara Medical University Advanced Emergency and Critical Care Medical Center during the period from March 2012 to February 2013 and treated within 24 hours of sustaining burn injuries. The total number of burn injury patients admitted to our center during this period was 25. Burn injuries in the body trunk were excluded from this study because the LDI and NIRS values obtained from them may be affected by the lung and/or the intestines. Since our intention was to measure LDI and NIRS focusing on burn sites in the 4 extremities we excluded those patients in whom these sites were not involved. Also excluded were patients administered drugs such as vasopressors and vasodilators during the measurement because of their effects on hemodynamics and skin blood flow. Further, patients with inhalation burn injury who showed hypoxia and/or carbon monoxide intoxication

were excluded. Finally, 14 patients with extremity burns regardless of the presence/absence of inhalation injury or trunk burns were included for this study.

Fifty lesion sites in these 14 patients were analyzed by LDI and NIRS. There were 8 men and 6 women with a median age of 58 years (range 7-89 years) and a median Burn Index of 17 (6-55). At the time of the LDI and NIRS evaluation the median blood Hb concentration was 14.5 g/dl (10.8-16.2), and the median systemic circulation SpO₂ was 98% (96-100) (Table 1).

Regional tissue blood flow (rTBF) and rSO₂ were measured by LDI and NIRS respectively within 48 hours of the burn injuries. The sites selected for the LDI and NIRS measurements were adequately rinsed beforehand, and any sites showing blisters or treated with ointment were excluded from the measurements. Then, to prevent any influence of this rinsing on the skin temperature and skin blood flow of the measured sites, for 1 hour afterwards the measured sites were protected with coating material. The patients were kept at rest, and with the systolic pressure maintained at ≥90 mmHg and the systemic circulation arterial blood SpO₂ at ≥96% rTBF and rSO₂ at the wound were measured.

Laser Doppler imaging (LDI)

LDI is already a well established non-contact blood flow imaging modality [2-7]. In LDI, a single wavelength laser beam is made to irradiate

intravascular red blood cells in the burn wound, and the reflected light is analyzed. This light is reflected back within irradiating fiberglass. The intensity of this reflected light, and discrepancies in the wavelength phase of the reflected and irradiating light are determined, the red blood cell mass and velocity are calculated, and the state of blood flow is imaged from these data (blood flow 2-dimensional image) [7]. The area targeted for measurement is located at a depth about 1~2 mm below the skin surface, and usually the blood flow of only the skin is measured, with the measurements not thought to be influenced by the deep organs. It takes about 4~10 minutes for the measurements when images are prepared in a 256x256 pixel format. In this study, a Moor Co. (UK) LDI2-IR was used. From the "flux" value obtained from the measurement a Perfusion Unit (PU) in the range of 0-1000 was calculated, and was considered to reflect rTBF. PU has been documented to accurately evaluate burn depth [7].

Near-infrared spectroscopy (NIRS)

NIRS uses near-infrared rays of 3 wavelengths (735, 810, 850 nm). The oxyhemoglobin and deoxyhemoglobin concentration ratio is calculated by spatial resolution in the entire tissue including arterial blood, vein, capillary, and bone, and the oxygen saturation of the entire tissue (regional mixed blood oxygen saturation: rSO₂) is measured. In the present study, a NIRO-200NX (Hamamatsu Photonics, Japan) was used. The surface of burn wound to be estimated by NIRS was covered with sterile sheet of transparent polyurethane film (3M™ Tegaderm™) for the indirect contact of the NIRS probes with the burn injury. The distance between the two NIRS probes (light emitting and detecting ones) were 3 cm, and thereby the current data for rSO₂ were supposed to be obtained from the tissue with a depth up to 2.1 cm beneath the probes.

rSO₂ measured by NIRS has been reported to be useful in diverse contexts such as for evaluation of cerebral blood flow in patients undergoing cardiopulmonary resuscitation [9, 10], and assessment of intramuscular blood flow in sports medicine [11, 12].

Statistical analysis

The correlation between rTBF (PU) measured by LDI and rSO₂(%) measured by NIRS was deter-

mined statistically using the statistical software package SPSS® (Version 11.0 for Windows, SPSS Inc., Chicago, IL).

Because of skewed data distributions and small sample sizes, nonparametric statistical procedures were used. The Spearman rank correlation coefficient was used to assess the association between rTBF (PU) and rSO₂(%). Also, since the oxygen saturation of the arterial blood in the systemic circulation differs between individual patients, we standardized burn wound rSO₂ values so as to exclude any influence of this systemic circulation SO₂ on wound SO₂. These values were obtained by dividing the burn wound rSO₂ by rSO₂ of uninvolved skin (rSO₂ ratio: burn wound rSO₂/normal site rSO₂). The correlation between this standardized rSO₂ and rTBF measured by LDI was also statistically. *P* value less than 0.05 was considered statistically significant.

Results

rSO₂ determined by NIRS showed a range of values of 50~83%, while PU obtained by LDI showed a range of values of 80~700.

The rSO₂ (perfusion unit; range, 61-704 and median, 406) by NIRS and the rTBF (%; 52-82, 72) by LDI in the severe burn lesions were positively correlated (*r*=0.755, *p*<0.001) (**Figure 1**). This statistically positive correlation remained significant (*r*=0.678, *p*<0.001) after the values of rSO₂ standardized by dividing them with ones from the contralateral or adjacent intact skin regions (**Figure 2**).

Discussion

In previously conducted studies [2-7] in which regional tissue blood perfusion was evaluated in acute phase burn sites by LDI to determine burn depth/severity, the diagnostic accuracy and reliability of this method were deemed to be high. Riordan et al. [3] compared burn depth judged by pathological examination of burn wound tissues under a microscope with blood flow determined by LDI in acute phase burn wounds, and found an extremely close correlation between the two. In this investigation Riordan et al. reported a sensitivity of 95% and specificity of 94% for LDI in the evaluation of burn depth. Moreover, Pape et al. [7] found a close correlation between rTBF (PU) of acute phase burn wounds as measured by LDI and the time needed for burn wounds to heal with

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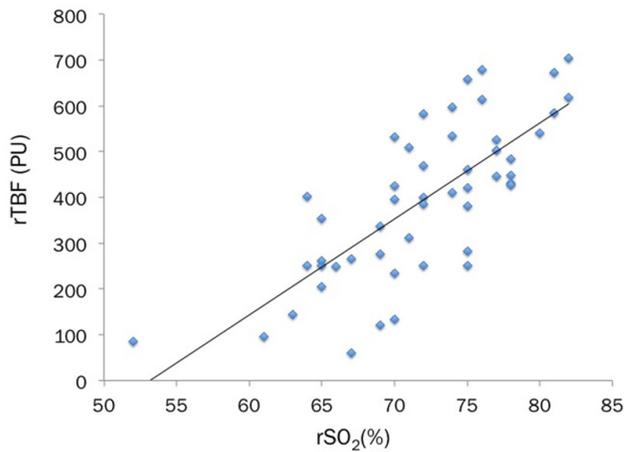


Figure 1. The rSO₂(%) measured by NIRS is compared to the rTBF (perfusion unit) by LDI in the 50 burn sites in 14 patients. The statistical analysis shows a significant positive correlation between these two values of rSO₂ and rTBF (Spearman rank correlation coefficient, $r=0.755$, $p<0.001$).

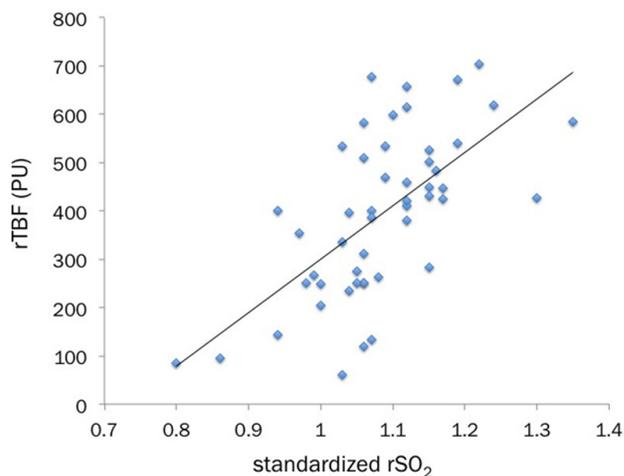


Figure 2. The standardized rSO₂ values (rSO₂ ratio; burn wound rSO₂/normal site rSO₂) also shows a statistically-significant positive correlation with rTBF (Spearman rank correlation coefficient, $r=0.678$, $p<0.001$).

conservative therapy alone. They also noted that acute phase LDI values shown by burn wounds that do not heal with conservative therapy alone exist. Such values obtained by LDI in the acute phase may be useful in judging the surgical indications for burn wounds. In this way, it has been considered that rTBF (PU) measured by LDI is useful in determining burn depth and in estimating the healing time. However, whether LDI will find a role as a widely applicable and versatile modality in the actual clinical setting remains to be clarified. The hurdle for its widespread use at the bedside in the inten-

sive care unit includes the size and cost of the LDI machine, and the fact that the time for LDI measurement is relatively long to apply for the restless patients such as babies.

On the other hand, NIRS to evaluate rSO₂ is already widely used in diverse clinical settings [8]. In recent years rSO₂ has also been used as an index of cerebral circulatory metabolism during resuscitation of cardiopulmonary arrest patients in the emergency outpatient clinic [9, 10]. Determining rSO₂ at the brain surface by attaching an NIRS measurement probe to the cardiopulmonary arrest patient's forehead makes it possible to estimate in real time the extent to which the cerebral circulation is being maintained. Similarly in the field of motor rehabilitation, by attaching a probe to muscles in the femoral or other sites and using measurements of rSO₂ as an index of changes in blood flow and oxygen metabolism associated with muscle contraction during exercise, NIRS has been found useful in assessing patients' state of recovery in a number of studies [11, 12]. The application of NIRS has been proposed in the field of burn injuries too [13-15]. In these reports, rSO₂ was suggested to closely correlate with macroscopic determinations of burn depth. However, no studies thus far have analyzed the correlation between rTBF (PU) measured by LDI and rSO₂ measured by NIRS in burn wounds. Already in the clinical setting there is anticipation that using highly versatile NIRS to evaluate rSO₂, the obtained value may facilitate judgment regarding the severity of burn wounds, thereby facilitating more appropriate therapeutic decision-making from the early phase of burn injury, more accurate estimates of prognosis, and better outcomes.

In the present study undertaken to explore a novel index to evaluate the severity of burn wounds, the rSO₂(%) value in burn wounds measured by NIRS was suggested to correlate extremely well with rTBF (PU) measured by LDI, which has previously been demonstrated to accurately evaluate burn depth. Moreover, since the oxygen saturation of the arterial blood in the systemic circulation differs between individual patients we standardized burn wound

rSO₂ values so as to exclude any influence of the systemic circulation SO₂ on wound SO₂ by dividing the burn wound rSO₂ by the rSO₂ of unaffected skin of each patient (burn wound rSO₂/normal site rSO₂). Subsequent analysis showed a close correlation between this rSO₂ ratio and rTBF (PU), with these results thus suggesting that NIRS, which is highly versatile in the clinical setting, may also be useful in assessing the severity of acute phase burns.

This study has several limitations. The number of studied patients was small, the correlation between acute phase burn wound rSO₂ and histological burn depth was not determined, the correlation between acute phase burn wound rSO₂ and the subsequent burn wound healing period was not analyzed, and the study focused solely on burn wounds of the extremities while not considering those of the trunk. In future, we plan to analyze greater numbers of cases and burn sites to address these limitations, and in this way better define the role of acute phase burn wound rSO₂ in the assessment of burn depth.

Conclusion

This study suggested the possibility that burn wound rSO₂ measured by clinically highly versatile NIRS may be as practical and useful as evaluation of burn tissue blood flow by LDI in the determination of burn depth. If these results using a practical modality such as NIRS to objectively evaluate the severity of acute phase burn wounds are reproduced, NIRS may facilitate decision-making in the early phase on the most appropriate interventions thereby helping to improve the therapeutic strategies and outcome of severe burn patients.

Disclosure of conflict of interest

None.

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