Laser speckle contrast imaging in children with scalds: Its influence on timing of intervention, duration of healing and care, and costs[☆]

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ABSTRACT

Background: Scalds are the most common type of burn injury in children, and the initial evaluation of burn depth is a problem. Early identification of deep dermal areas that need excision and grafting would save unnecessary visits and stays in hospital. Laser speckle contrast imaging (LSCI) shows promise for the evaluation of this type of burn. The aim of this study was to find out whether perfusion measured with LSCI has an influence on the decision for operation, duration of healing and care period, and costs, in children with scalds.

Methods: We studied a group of children with scalds whose wounds were evaluated with LSCI on day 3–4 after injury during the period 2012–2015. Regression (adjustment for percentage total body surface area burned (TBSA%), age, and sex) was used to analyse the significance of associations between degree of perfusion and clinical outcome.

Results: We studied 33 children with a mean TBSA% of 6.0 (95% CI 4.4–7.7)%. Lower perfusion values were associated with operation (area under the receiver-operating characteristic curve 0.86, 95% CI 0.73–1.00). The perfusion cut-off with 100% specificity for not undergoing an operation was ≥191 PU units (66.7% sensitivity and 72.7% accurately classified). Multivariable analyses showed that perfusion was independently associated with duration of healing and care period.

Conclusion: Lower perfusion values, as measured with LSCI, are associated with longer healing time and longer care period. By earlier identification of burns that will be operated, perfusion measurements may further decrease the duration of care of burns in children with scalds.

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1. Introduction

Scalds are the most common burn injury among toddlers [1,2], and their management includes several visits to the burn centre or overnight admission. Uncomplicated burns should heal within two weeks of injury [3]. The treatment is usually conservative, but some children are treated with excision of deeper burns and application of an autologous skin graft [1]. Our treatment is based mainly on outpatient procedures because the percentage total body surface area (TBSA%) burned is small. Because of this, measurement of outcome variables other than duration of hospital stay (such as care period and healing time) has been suggested [3].

A difficulty that clinicians face every day is correct staging of the depth of scalds [4,5], and when to make the decision about whether to operate [6,7]. Often conservative treatment is recommended to avoid unnecessary operations, but in many cases this will delay the decision. Unnecessary delay results in higher costs, and may worsen the final outcome of scars [8–10].

Previous studies have shown that perfusion measured with laser Doppler imaging (LDI) and laser speckle contrast imaging (LSCI) on days 3–4 after injury can assist in the assessment of depth of the burn, and early identify areas that could benefit from excision and autograft [11,12]. Whether the perfusion measured on days 3–4 is related to different outcome measures has not to our knowledge been studied previously for assessments of LSCI.

The aim of this study was therefore to find out whether perfusion measured with LSCI is helpful in deciding surgery and whether they are associated with healing time, care period, and costs, in children with scalds.

2. Methods

All children with scalds who presented to a University Hospital Burn Centre during the years between 2012–2015, were admitted for overnight stay or treated as outpatients, and had their burns evaluated with LSCI on day 3–4 after injury, were included. Patients who met the inclusion criteria were selected retrospectively for further analysis. The study was approved by the Regional Ethics Review Board (number 2012/31–31).

2.1. Care of the burn

According to local guidelines children with burns are usually treated mainly as outpatients [3]. This refers to burns that are less than 5% TBSA, and do not undergo immediate intervention or intravenous fluids, antibiotics, or other drugs. The children who do not fulfil these criteria are admitted to the paediatric care unit and managed by the plastic surgeons together with the paediatrician.

The patients' burns were treated according to a previously-described protocol [1–3]. All burns were treated conservatively for 14 days, in the hope of spontaneous healing, unless the attending surgeon thought that the wound was unlikely to heal in less than 21 days. In that case the burns were immediately treated by excision and autologous skin grafting.

Superficial dermal burns were dressed using a silicone based dressing or (in the case of suspected infection) a foam dressing containing silver. The dressings were changed 2–3 times/week. Deeper burns were cleaned and covered with xenografts under general anaesthesia or sedation, in the operating theatre. The wounds were then covered with a nylon mesh and wrapped with normal sterile gauze followed by elastic stockings or elastic bandages.

2.2. Laser speckle contrast imaging

A laser speckle contrast imager (LSCI, Pericam PSI, Perimed AB, Järfälla, Sweden) was used to measure perfusion. The system uses a divergent laser beam at a wavelength of 785 nm to create a speckle pattern in the illuminated area. It uses two cameras, one that captures the speckle contrast image, and the other that captures a conventional colour image of the area.

The size of the image was set to an area of 12×12 cm, the distance between the camera and the skin varied between 18–27 cm, and the acquisition rate was set to 21 frames/s. With each measurement, the system calculated the mean perfusion from 42 consecutive images, which resulted in a measurement time of 2 s for each scan. The spatial resolution of the perfusion image was roughly 0.2 mm/pixel at the selected distance. The LSCI system was calibrated at regular intervals as recommended by the manufacturer.

Regions of interest (ROI) were outlined in each image using the system's software (PIMSoft 1.5 Perimed AB, Järfälla, Sweden). Several images were usually acquired from the same patient and each image often had multiple ROI, which corresponded to areas of clearly different perfusion. ROI were marked so that all different homogeneous perfusion areas with a diameter of at least 2 cm were shown. Sometimes there were several areas with similar perfusion, but in different anatomical sites; in these cases, each area contributed to one ROI. The mean perfusion was calculated for each ROI, and each one was outlined by the second author (RM). The measurement was done 3–4 days after injury and the lowest perfusion unit (PU) value for each patient was used in the study.

2.3. Outcome variables

The variables "TBSA%" and "extent of superficial and deep dermal burns" were recorded on admission in the local burn registry (which is maintained prospectively) on a detailed Lund & Browder chart [13]. "Operation" was defined as excision and skin graft using an autograft. "Healing time" was defined as the time (days from injury) to complete re-epithelialisation of the wound. The "care period " was defined as the duration of care from the first visit or overnight hospital stay to the last visit [3].

We used daily recordings of the burn intervention score [13,14] to calculate costs. The score, which is a combined measure of resources used and severity of illness, forms the basis for charging for each patient. To standardise the economic variable over the study period we applied the monetary value from the year 2017 at each score point and converted to US\$ according to the exchange rate in June 2017.

2.4. Statistics

The significance of differences between groups was assessed using Student's t test for independent samples. Distribution was tested

with the Lilliefors test for normality. Logistic regression was used to analyse the significance of the association between perfusion and categorical outcome measures, and receiver operating characteristic curves (area under the curve) (ROC AUC) were calculated after the logistic regression. Nonparametric ROC analysis (roctab) was used to calculate perfusion cut-off for operation. Linear regression was used to assess continuous outcome measures. Multivariable regression was used to analyse the effect of perfusion further after it had been adjusted for other potentially relevant variables (TBSA %, superficial dermal and deeper burns, age, and sex). Probabilities of less than 0.05 were accepted as significant. Data were analysed using STATA (STATA v12.0, Stata Corp. LP, TX, USA)

3. Results

We studied 33 children, of whom 18 were boys (55%), mean age was 2.4 (95% CI 1.8–3.0) years, and mean TBSA% 6.0 (95% CI 4.4–7.7)%. Six of the patients underwent excision and skin grafts using autografts, mean duration of wound healing was 17.7 (95% CI 13.9–21.5) days, mean care period was 15.7 (95% CI 12.5–18.9) days, and mean charging costs were US$ 14 011 (95% CI 9970–18053) (Table 1).

3.1. Operation

Perfusion was lower in children who underwent excision and grafting (n=6) compared with those whose wounds healed spontaneously: 111 PU (95% CI 66–156) and 240 PU (95% CI 194–285), respectively (p=0.01, Fig. 1). Of the 27 children whose wounds healed spontaneously, nine had wounds with perfusion in the same range (range 69–158) as the children who underwent surgery. Three of these nine had healing times between 14 and 20 days while four had healing times that exceeded 20 days (Fig. 2). Nonlinear logistic regression showed an increased risk for operation with lower perfusion (Tables 2a and 2b), and the predictive value for operation was (AUC) 0.86
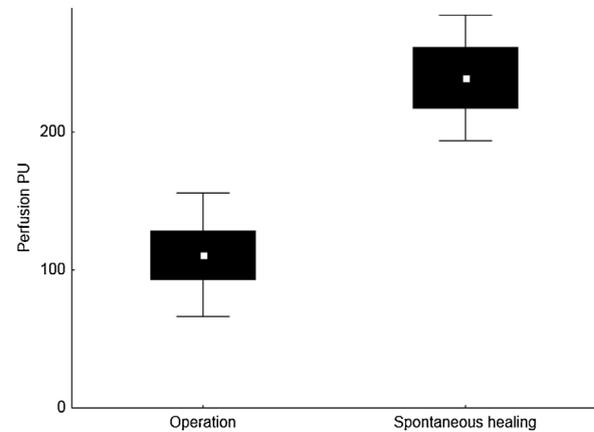

Fig. 1 – Perfusion values among the patients grouped by operation (range 60–173) and spontaneous healing (range 69–458). Box=mean (SE), whiskers=95% CI.
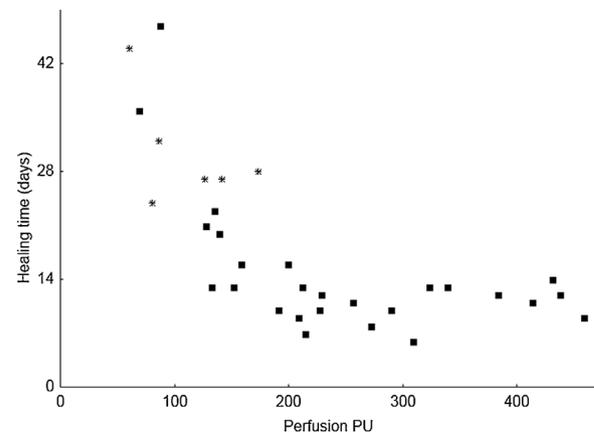

Fig. 2 – The association between duration of healing (y-axis) and perfusion (x-axis), grouped by operation (stars) and no operation (closed squares). One patient was excluded in this scatterplot because of a value of the exact healing time was missing.

Table 1 – Details of the patients (n=33).	
Age (years)	1.7 (1.3–3.7)
Male sex	18
TBSA%	4.5 (3.0–8.0)
Superficial dermal BSA%	4.0 (2.0–8.0)
Deep dermal and full thickness BSA%	0 (0–0.3)
Perfusion, lowest PU day3–4	208 (135–289)
No of patients with operation	6
Healing time (days)	13.0 (10.5–23.5)
Care period	11.0 (9.0–24.0)
Care days	6.0 (4.0–10.0)
Hospital stay (days)	2.0 (0–5.0)
Number of visits	3.0 (2.0–5.0)
Charging costs (US$)	10,031 (7165–17,673)

Data are presented as median 25–75 centiles, or n. TBSA% =percentage total body surface area burned. BSA=body surface area. Healing time=the duration between injury and when the burn wound was healed. Care period=the duration between the first and last visit for burn care. Care days=the duration of overnight stay plus the number of visits for procedures. Hospital stay=the duration of overnight stay.

Table 2a – Multivariable logistic regression for operation.				
	Coefficient	p Value	OR	95% CI
Perfusion (PU)	0.02	0.10	1.02	1.00–1.05
TBSA%	−0.24	0.12	0.79	0.59–1.06
Age (years)	−0.49	0.16	0.61	0.31–1.22
Constant	1.34	0.54	3.83	0.06–264.3

Pseudo R-square 0.46, model p=0.002. Operation code=0, no operation=1. Perfusion values (continuous) were used in this regression as the cut-off predicted success perfectly.

Table 2b – Logistic simple regression for operation.				
	Coefficient	p Value	OR	95% CI
Perfusion (PU)	0.02	0.04	1.02	1.00–1.04
Constant	−1.94	0.17	0.14	0.01–2.32

Pseudo R-square 0.30, model p=0.002. Operation code=0, no operation=1. Perfusion values (continuous) were used in this regression as the cut-off predicted success perfectly.

(95% CI 0.73–1.00) (goodness-of-fit chi square 20.6, p=0.92). The AUC increased to 0.90 (95% CI 0.76–1.00) when adding TBSA% to the regression model, and to 0.91 (0.79–1.00) when also adding perfusion, TBSA% and age. The increase in AUC by adding TBSA% and age to the model was, however, not significant.

Based on the results of the regression analysis, the equation to predict the probability of no operation (Fig. 3) for a given patient was calculated as:

$$P_{no\ operation} = \frac{e^{0.022PU+1.9374}}{1 + e^{0.022PU+1.9374}}$$

where PU is defined as the lowest measured perfusion value on day three after injury.

The perfusion cut-off which predicted operation or no operation with the highest accuracy was 151 PU units (sensitivity 74.1%, specificity 83.3%, and 75.8% accurately classified). The cut-off value with 100% specificity for not undergoing an operation was 191 PU units (66.7% sensitivity, 72.7% accurately classified). We chose to use the higher cut-off in the regressions as it performed better (higher R^2).

3.2. Healing time

When the patients were grouped by healing times of less than 14 days and 14 days or more, perfusion values were higher in the group with the shorter healing time: (mean) 280 PU (95% CI 232–328), and (mean) 139 PU (95% CI 89–189), respectively, t test p<0.001. Simple linear regression showed that lower perfusion was associated with longer duration of healing, in that a perfusion <191 PU corresponded to a (mean) 15.6 days difference in healing time (Tables 3a and 3b).

3.3. Care period

Lower perfusion was associated with a longer care period (Fig. 4). A perfusion <191 PU corresponded to a (mean) 14.4 days difference in the period of care (Tables 4a and 4b).

3.4. Charging costs

Lower perfusion was associated with higher cost (Fig. 5), in that a perfusion value <191 PU corresponded to a difference in cost

Table 3a – Multivariable regression for healing time.

	Coefficient	p Value	95% CI
Perfusion (PU)[a]	−14.46	<0.001	−20.74 to −8.17
TBSA%	0.14	0.68	−0.56 to 0.84
Age (years)	−0.42	0.58	−1.95 to 1.10
Male sex	4.20	0.12	−1.22 to 9.62
Constant	23.67	<0.001	15.46–31.89

Adjusted R-square 0.55, model p<0.001.
[a] Perfusion cut-off PU<191=code 0, PU≥191=code 1.

Table 3b – Simple regression for healing time.

	Coefficient	p Value	95% CI
Perfusion (PU)[a]	−15.61	<0.001	−20.80 to −10.42
Constant	26.50	<0.001	22.61–30.39

Adjusted R-square 0.54, model p<0.001.
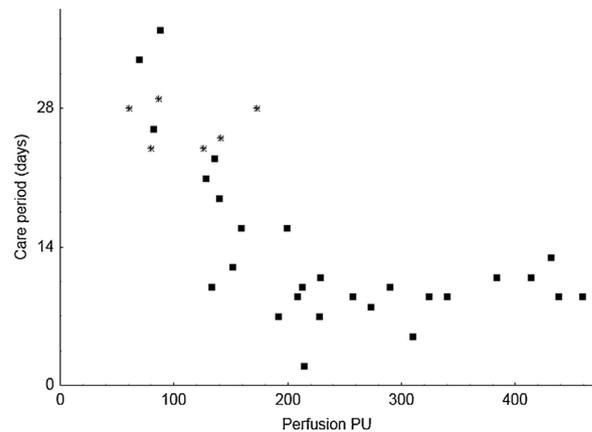[a] Perfusion cut-off PU<191=code 0, PU≥191=code 1.

Fig. 4 – The association between care period (y-axis) and perfusion (x-axis), grouped by operation (stars) and no operation (closed squares).
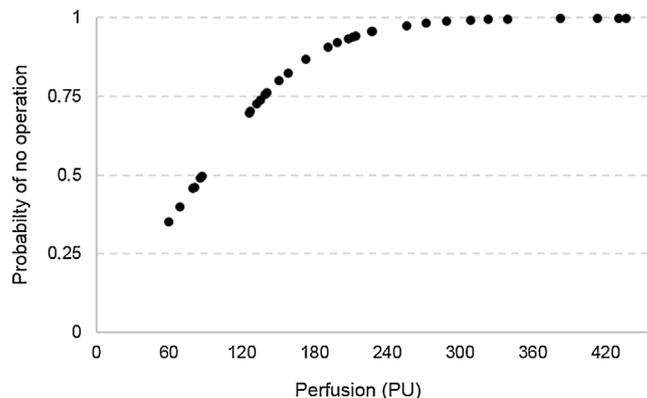

Fig. 3 – The figure shows the probability (logistic regression) of operation calculated on the lowest perfusion unit (PU) value (x-axis) on day three after injury. Y-axis 0=100% probability for operation, 1=100% probability for no operation.

**Table 4a – Multivariable regression for care period.**

	Coefficient	p Value	95% CI
Perfusion (PU)[a]	−12.69	<0.001	−17.14 to −8.23
TBSA%	0.29	0.24	−0.21 to 0.78
Age (years)	−0.33	0.54	−1.41 to 0.76
Male sex	3.37	0.08	−0.41 to 7.15
Constant	19.84	<0.001	14.05–25.63

Adjusted R-square 0.68, model p<0.001.
[a] Perfusion cut-off PU<191=code 0, PU≥191=code 1.

Table 5a – Multivariable regression for charging costs (US$).

	Coefficient	p Value	95% CI
Perfusion (PU)[a]	−5838	0.09	−12703 to 1028
TBSA%	1321	<0.001	59–2083
Age (years)	913	0.27	−758 to 2587
Male sex	1883	0.51	−3936 to 7702
Constant	6042	0.18	−2874 to 14959

Adjusted R-square 0.53, model p<0.001.
[a] Perfusion cut-off PU<191=code 0, PU≥191=code 1.

Table 4b – Simple regression for care period.

	Coefficient	p Value	95% CI
Perfusion (PU)[a]	−14.43	<0.001	−18.22 to −10.64
Constant	23.60	<0.001	20.80–26.40

Adjusted R-square 0.65, model p<0.001.
[a] Perfusion cut-off PU<191=code 0, PU≥191=code 1.

Table 5b – Simple regression for charging costs (US$).

	Coefficient	p Value	95% CI
Perfusion (PU)[a]	−13252	<0.001	−19932 to −6573
Constant	21240	<0.001	16307–26173

Adjusted R-square 0.32, model p<0.001.
[a] Perfusion cut-off PU<191=code 0, PU≥191=code 1.
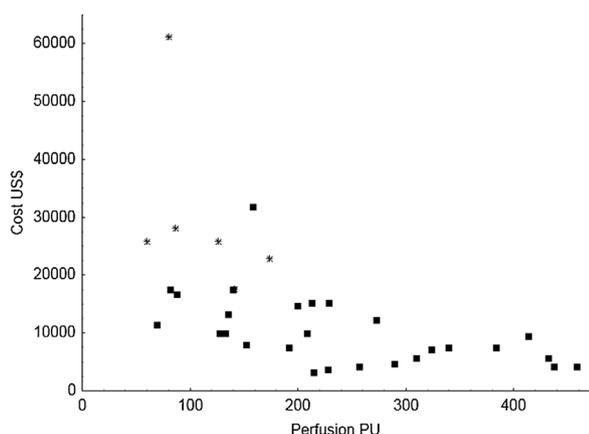
Fig. 5 – The association between cost (y-axis) and perfusion (x-axis), grouped by operation (stars) and no operation (closed squares).

of (mean) 13252 US$ (Tables 5a and 5b). The cost for one patient was five times higher than the median (Fig. 5 and Table 1). This patient had 13.5% TBSA, the longest duration of hospital stay (22 days), was treated with two operations and six wound care procedures under sedation, and had a central venous line for administration of fluids and nutritional support.

3.5.   Multivariable analyses

Multivariable regression showed that lower perfusion values were associated with both longer healing time as well as a longer period of care (Tables 3a and 4a). The association with charging cost was not significant after adjustment for TBSA% (Table 5a).

We removed the variable sex from the logistic regression for operation, because all operations were done in boys and so statistical software omitted this variable. In parallel with the final model in which TBSA% was used, we made analyses with the two variables "superficial dermal BSA%" and "deep dermal and full thickness BSA%" (the sum of these amounts being the TBSA%) to find out if the deep burns were a better predictor of clinical outcomes than TBSA% and perfusion. We chose to use TBSA% in the final model as the use of the other two variables did not change the association between perfusion and the different clinical outcomes. The level of significance did not differ either, when compared with that of TBSA%, and it was only the variable "superficial dermal BSA%" that was significant, with numbers similar to those for TBSA%.

4.   Discussion

We studied the association between different outcome variables of care of burns in scalded children and perfusion of the wound measured by LSCI. The longer healing time and care period, as well as surgical treatment of deeper injuries, were associated with low perfusion values on days 3–4 after injury. The statistical model further validated the role of LSCI in the early surgery decision-making after scalds. This will enable future comparison of results in terms of decreased care days, and decreased economic costs when LSCI is implemented for early surgery decision-making in this group of burned patients.

4.1.   The use of LSCI in a group in which surgery is to be minimised

The diagnosis of the depth of the burn in children with scalds is difficult, particularly deep dermal burns. Clinically, capillary refill and evaluation of the moisture and colour of the wound are used to assess them, but though they are simple and cost-effective, they fail to detect depth correctly in many cases [15]. Dermal burns are usually difficult to evaluate [7] which may further delay the decision to operate, and thereby potentially delay the healing process and promote the development of

hypertrophic scarring [6,16]. Methods that can better verify the burn depth in these types of injuries have therefore been sought for several decades. Recent publications have discussed the role of LSCI in assessment of the depth of burns [17,18], and recommend its use in children with scalds [12]. Its role, however, needs validation to prove its association with outcome measures in burn care. In a study by Kim et al. [19] the authors showed that by using LDI they could shorten the time to operation in children with burns, which in turn can shorten the duration of hospital stay. In this study we aimed to validate the association between assessment of the burn with LSCI and other outcome measures such as healing time.

4.2. The association between operation and perfusion

Previous studies have investigated the association of low perfusion values measured with LSCI/LDI and the decision to operate [12,19], and they used the perfusion patterns of the skin between 72–96h after injury to predict depth of burn and outcome of healing. In short, decreased perfusion indicated increased depth. The assessment was also improved if early measurements were made. Our simple regression analysis showed that low perfusion values, as measured with LSCI, strongly predicted which patients who would undergo an operation. Although we did not have sufficient power in the study to reach significance in the multivariable model for operation, the simple regression showed a significant association and a good AUC. This method of statistics is extremely reliable and encourages us to extend the use of LSCI as a routine diagnostic tool in our clinic.

4.3. Optimising surgical interventions using LSCI

Prolonged healing time, particularly in scalds, is usually an indicator of deeper burns, subsequently undergoing excision and skin graft. The use of LSCI clinically as routine could potentially add the advantage of optimising the timing of operation. Early excision and skin graft of deeper dermal burns would avoid unnecessary visits to hospital, and decrease the need for repeated care of the wound under general anaesthesia. We found a clear association between low perfusion values and longer healing time, as well as longer care period, which further supports the value of LSCI in clinical use. The wounds of patients who were not operated on, despite having lower perfusion values, took longer to heal. This further indicates that LSCI is a valuable tool in deciding between operation and conservative treatment in borderline cases.

As has been shown before [11], the measurement of perfusion at days 3–4 after injury was helpful in deciding which parts of the burn that were deeper. This time window can probably be extended further to 2–5days according to perfusion trends described in scalds using both LDI and LSCI [11,18]. The decrease in perfusion seen during the first few days after injury in deeper scalds has been linked to a process called "burn wound conversion". This process occurs mainly in scalds, but also to some degree in burns of other causes [20–22]. A previous LSCI study reported that a decrease in perfusion values during the first four days after injury is associated with surgical excision later on among children with scalds [12]. These findings are likely related to the process of ongoing burn wound conversion.

4.4. Limitations

The main limitations of our study were the small number of cases and the retrospective design. Another possible limitation is that we did not use the cut-off value for perfusion change, −0.35, which was developed in a previous study. Perfusion change is calculated by combining two measurements over time (on admission and on day 3–4) into a modified perfusion trend to predict operation, which was defined as excision and autograft or delayed healing >20 days. Values lower than the cut-off were associated with operation [12]. We chose to not use that equation in the present study because it would have decreased the study group by 50% because, for many patients, perfusion measurements were done only after 3–5days and not on admission. Another difference compared with our previous study is that we defined operation differently. In our previous study, it was defined as an actual operation, or healing on the 20th day or later. In the current study, only actual operations were considered.

We are aware of the difficulties with reporting charging costs [23]. First, health care financial systems differ between countries, as do their methods of charging. Secondly, it is not possible to calculate the actual cost for each patient or intervention as health care (except for personnel costs, costs for medical disposable material, and medical equipment). Actual cost also depends on clinical skill and knowledge, which includes costs for development and research. However, the focus of this study was not to present a cost analysis, it was to study the association between perfusion and clinical outcome, of which we think this variable gives an interesting perspective by adding an analysis of the relative amount of resources to the analysis of the time variables.

Long-term evaluation of healing and scarring in these patients would have been a valuable outcome to investigate further. To do a prospective, randomised, clinical trial, where clinical decision-making is based on LSCI, would therefore be interesting and confirm the usefulness of LSCI in a clinical setting.

5. Conclusion

Lower perfusion values, as measured with LSCI, are associated with longer healing time and longer care period. By earlier identification of burns to be operated, perfusion measurements may further decrease the duration of care of burns in children with scalds.

Conflict of interest

We have no conflicts of interest.

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