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A prospective study comparing the FLIR ONE with laser Doppler imaging in the assessment of burn depth by a tertiary burns unit in the United Kingdom

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Abstract

Introduction: Laser Doppler imaging (LDI) is the 'gold standard' tool for the assessment of burn depth. However, it is costly. The FLIR ONE is a novel, mobile-attached, thermal imaging camera used to assess burn wound temperature. This study compares the FLIR ONE and LDI in assessing burn depth and predicting healing times.

Methods: Forty-five adult patients with burn wounds, presenting at 1–5 days, were imaged with the FLIR ONE and LDI. Infected, chemical and electrical burns were excluded. Healing potential was determined by comparing wound and normal skin temperature for the FLIR ONE and blood flow changes with the LDI. Healing potential was categorised into wounds healing in less than and over 21 days. Pearson's test was used to determine the correlation between changes in wound temperature and healing potential.

Results: Percent total body surface area (%TBSA) was in the range of 0.5–45. FLIR demonstrated a sensitivity of 66.67% and specificity of 76.67% in predicting healing within 21 days, while LDI demonstrated a sensitivity of 93.33% and specificity of 40%. The FLIR ONE showed a significant difference in the mean temperature changes between burns that healed in less than (0.1933 ± 0.3554) and over 21 days (–1 ± 0.4329) (P = 0.04904). Pearson's test showed a significant correlation between the difference in wound and normal skin temperature with healing times (P = 0.04517).

Conclusion: The inexpensive FLIR ONE shows a significant correlation between changes in wound temperature and healing times. It is useful in predicting healing within 21 days. However, evaporative cooling at the wound surface can lead to overprediction of healing times and overtreatment.

Keywords

FLIR ONE, burn depth, healing potential, laser Doppler imaging, thermal imaging, MOOR LDI

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Lay Summary

Background

Laser Doppler imaging is currently the main tool for burn depth assessment. It works by analysing the blood flow in a burn wound. Based on these findings, it can predict the depth of the burn injury and predict if it will heal in less than or over 21 days. The main problem is that it is costly. The FLIR ONE is a novel, mobile-attached, thermal imaging camera. It can be used to assess burn depth by comparing the temperature of the burn wound to the surrounding normal skin. This information can then be used to predict healing times into less than and over 21 days.

The issue being explored

The usefulness of the FLIR ONE in assessing burn depth and predicting healing time when compared to the LDI.

How was the work conducted?

Forty-five adult patients who sustained a burn injury within the last five days were imaged with both the FLIR ONE and LDI. Those with infected, electrical or chemical burns were excluded. Healing potential was determined by comparing the temperature of the burn wound with normal skin for the FLIR ONE and by changes in wound blood flow with the LDI. Healing potential was categorised into wounds healing in less than and over 21 days. The correlation between the temperature changes of the burn wound and healing time was evaluated for the FLIR ONE.

What we learned from the study

This study was able to demonstrate that the FLIR ONE showed a significant correlation between the temperature difference between the burn wound and normal skin with healing times. When compared with the LDI, the FLIR ONE was useful in predicting if a burn wound will heal in less than 21 days. The FLIR ONE has advantages over the LDI, it is low cost, portable and produces instantaneous images. Ultimately, this developing technology may increase access to higher standard burn care in centres where LDI is not affordable.

Introduction

Differentiating between full-thickness burns from superficial type burns is relatively easy. The challenge remains in the diagnosis of intermediate-depth burns. The accuracy of this differentiation has great clinical significance as it determines the management and predicted healing times for the burn injury. Laser Doppler imaging (LDI) is the National Institute for Health and Care Excellence (NICE) recommended 'gold standard' for aiding clinicians in assessing the depth and healing times of burns injuries.[1] LDI in the application of determining burn depth has shown to have 97% accuracy, compared to 71.4% accuracy by experienced clinicians.[2] The Moor Laser Doppler Line Scanner, a version of LDI, can measure the blood flow in the microvasculature[3] in a burn wound to predict burn depth and healing time. The use of Doppler imaging to analyse blood flow in capillaries was first described by Essex and Byrne in 1991.[4]

While LDI has shown high clinical accuracy,[2] it has some significant limitations. The device is costly, in the range of tens of thousands of pounds.[5] The cost alone can act as a barrier to entry for many centres in the United Kingdom and abroad. LDI also has other limitations, including high maintenance costs.[5] It is a large device that can be difficult to move between rooms. It requires the patient to remain still for several seconds, even though the patient might be in significant pain from the burn injury, making it particularly challenging to image young children. The impracticality contrasts with the FLIR ONE, which is a smartphone-attached thermal imaging camera that uses the infrared waves emitted from a source to determine its temperature. The FLIR ONE is very portable and can fit into one's pocket; it can be purchased for £219.99 at the time of writing,[6] and takes instantaneous images and offers a spot temperature measurement.[7]

Thermal imaging has been widely documented in the analysis of burn wound injuries. The concept of using thermal imaging for burn wound analysis was initially described in 1961 in animal models.[8] Thermography was evaluated

for determining burn injury in human patients in 1966.[9] This initial clinical trial showed that there was a role for thermography in the evaluation of burn injuries.

Other thermal imaging cameras from FLIR Systems have shown success in predicting burn wound healing times in other studies. A 2013 study, consisting of 11 patients, used a higher resolution FLIR camera (FLIR SC660, FLIR Systems, Wilsonville, OR, USA). This study concluded that it could correctly categorise burns into full-thickness, deep dermal and superficial partial-thickness burns based on the temperature difference compared with unburnt skin.[10] A study published in *Burns* in 2016 showed that the FLIR T650 (FLIR T650, FLIR Systems) was useful in aiding the prediction of healing time for 32 burn injuries.[11] A study conducted in The Netherlands used the FLIR ONE and was able to show that the device is highly reliable in the prediction of burn would healing time but demonstrates moderate validity.[12]

The aim of this study is to compare the effectiveness of the FLIR ONE device in assessing burn depth and therefore predicting healing times based on wound temperature compared with the Moor LDI. This study also aims to determine if there is a statistically significant difference in mean burn wound temperature when using the FLIR ONE device for burns healing in less than 21 days compared to burns healing in more than 21 days. Twenty-one days was used as the cut-off point for this study as a burn that takes over 21 days to heal will more likely develop hypertrophic scarring and hence is a relative indication for surgical excision and grafting.

Methods

Patients aged 18–79 years, with burn wounds between one and five days old, who attended the outpatient department at St Andrew's Centre for Burns and Plastics at Broomfield Hospital were consented to participate in the study. This research is National Research Ethics Committee approved. Electrical, chemical and infected burns were excluded. These exclusion criteria fit in with the guidelines for the use of the Moor Laser Doppler Line Scanner (moorLDLS2, Moor Instruments Ltd, Axminster, Devon, England). Clothes were removed for 3 min before any of the images being taken to allow the skin to acclimatise. During the patient's first outpatient appointment, images were taken by the Moor LDI and the FLIR ONE camera (FLIR ONE 1st Generation, FLIR Systems) attached to an iPhone 5 (Apple iPhone 5, Apple, Apple Inc., Cupertino, CA, USA). The FLIR ONE was operated through the iPhone 5 using the FLIR ONE mobile application for iOS (FLIR ONE v3.0.80, FLIR Systems). Images were taken 1–5 days post burn as reported by the patient. Both photos were taken with an ambient relative humidity of less than 30%. To limit inter-user variability, the images were taken by the same user who was called to attend at each patient's presentation. The colour palette of the FLIR ONE images was set such that blue indicated the coldest temperature, followed by green, yellow, red and white showing the hottest temperature.

The Moor Laser Doppler Line Scanner was then used to group each burn injury into predicted healing times of less than 21 days and those more than 21 days.

The FLIR ONE images were analysed with the help of the FLIR Tools mobile application (FLIR Tools v 1.8.3, FLIR Systems). The FLIR Tools app was used to calculate a mean temperature of the burn wound area. This was then compared with the spot temperature of a normal patch of skin away from the burn site. We then calculated the average mean temperature difference between burn wound and normal skin for wounds that healed in less than and over 21 days. This mean temperature difference of –1 °C was used as a cut-off value to calculate the sensitivity and specificity of the FLIR device. Previous studies using infrared technology to analyse burns suggested that a temperature difference greater than –1.2 °C between the burned and normal skin suggested a deep dermal injury.[10] This figure was similar to our cut-off temperature of –1 °C, which we used as a surrogate marker of healing time of fewer than 21 days. The FLIR Tools app is a computer or mobile-based software that allows the user to import images that have been taken with the FLIR ONE. Using this software, the user can calculate a more accurate mean burn wound temperature measurement than just using the FLIR ONE mobile application. Figure 1 shows the use of the FLIR Tools app to provide a more precise mean burn wound temperature measurement.

Statistical analysis was completed using GraphPad Prism v7.04 (GraphPad Software, La Jolla, CA, USA). An unpaired t-test was used to compare the mean temperature difference between the burn temperature and normal skin temperature in each category of predicted healing time (burns healing in less than 21 days or burns healing in over 21 days) for the FLIR ONE device. Pearson's test was used to determine if there was a correlation between temperature difference (between burned skin and normal skin) and a healing time for the FLIR ONE device. Statistical significance was considered at a probability of $P < 0.05$.

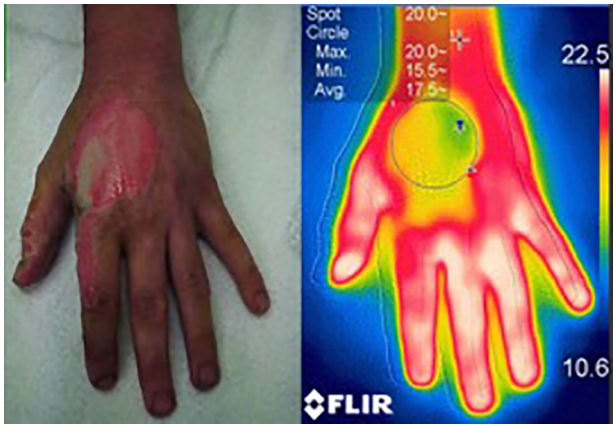

Figure 1. A real image of a burn wound compared with a thermographic image of the same wound taken with the FLIR ONE and imported into the FLIR Tools mobile application for more accurate mean burn temperature measurement.

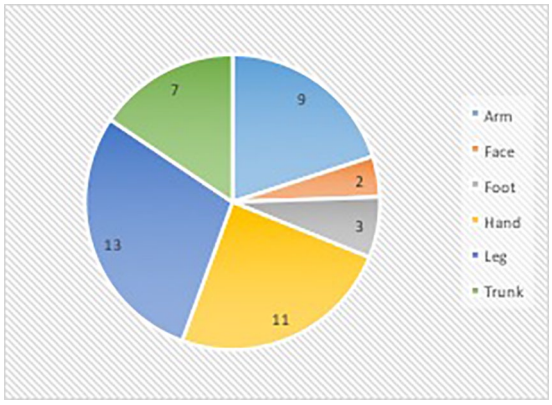

Figure 2. A pie chart showing the proportion of total burn injuries represented by each anatomical region.

Results

Forty-five patients (23 men, 22 women) were recruited to the study. FLIR ONE and LDI Images were taken on the first presentation to the burns centre 1–5 days after the burn injury. The percentage total body surface area (%TBSA) was in the range of 0.5–45. Forty-one of the patients had %TBSA < 5%, two patients had a %TBSA in the range of 5%–10%, one patient had %TBSA of 20% and one had a %TBSA of 45%. As demonstrated by Figure 2, 13 of the burns were located on the legs, 11 on the hands, nine on the arms, seven on the trunk, three limited to the feet and two on the face. The mechanism of burns included scalds, contact burns, flame injuries and flash injuries. As per the exclusion criteria, electrical, chemical and infected burns were excluded. The ambient relative humidity in the room at the time of assessment was in the range of 13.6%–27.8%.

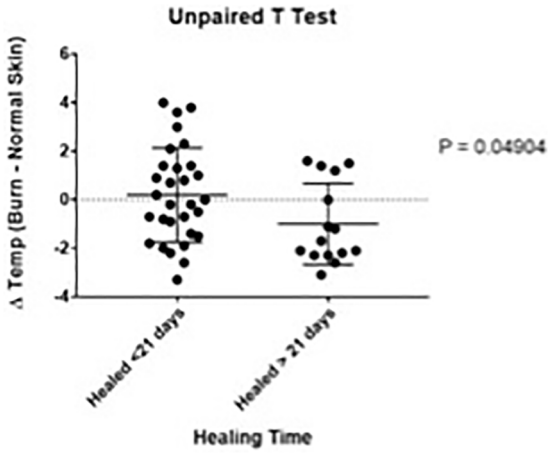

Figure 3. An unpaired t-test comparing the mean temperature difference between burns healing in under and over 21 days compared with normal skin. The mean temperature difference between the two categories of healing time was shown to be statistically significant ($P = 0.04904$) at approximately 1 °C.

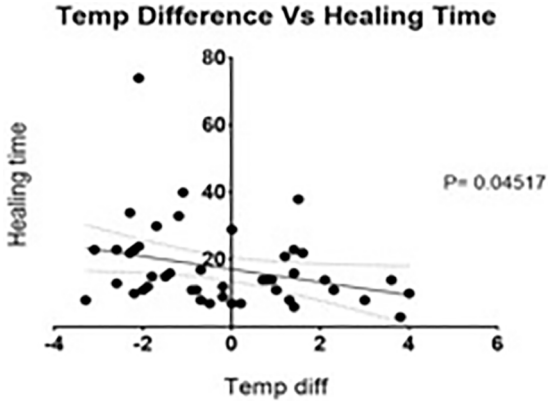

Figure 4. A diagram depicting Pearson's test showing that there is a statistically significant ($P = 0.04517$) difference between healing time and burn temperature compared with normal skin. This is as expected as you would expect a burn that is cooler compared with normal skin, to heal in a longer time period.

The FLIR ONE demonstrated a sensitivity of 66.67% (95% confidence interval [CI] = 52.71–89.86) and a specificity of 76.67% (95% CI = 12.52–to 85.51) in predicting that a burn injury would heal within 21 days. The LDI demonstrated a sensitivity of 93.33% (95% CI = 72.71–99.86) and a specificity of 40.00% (95% CI = 15.70–84.30) in predicting that a burn injury would heal within 21 days.

An unpaired t-test showed (Figure 3) there was a statistically significant difference in the mean temperatures between burns that healed in under 21 days (0.1933 ± 0.3554) and over 21 days (–1 ± 0.4329) ($P = 0.04904$). Pearson's test (Figure 4) showed a significant correlation between the dif-

Figure 5. The image of the same injury by the FLIR ONE on the left and the MOOR LDI on the right. It can be seen that the warmest area on the FLIR ONE image corresponds with the warmest region according to the MOOR LDI.

ference in burn wound and normal skin temperature with healing times ($P = 0.04517$).

Discussion

The unpaired t-test (Figure 3) shows that there is a statistically significant difference of approximately 1 °C between burns healing in less than 21 days and burns healing in over 21 days. Pearson's test in Figure 4 shows that there is a statistically significant correlation showing that the warmer the burn injury compared with normal skin, the shorter the healing time. This is as expected, as one would predict a shorter healing time the closer the burn wound temperature is to that of normal skin.

A 2017 Dutch study, also looking at the FLIR ONE, found with statistical significance that burns healing in over 21 days were on average –1.15 °C cooler than burns healing in less than 21 days.[12] The similarity between the mean temperature difference between the burn wound and normal skin in this Dutch study and our study was of 1.15 °C and 1 °C, respectively. The findings suggest that thermal imaging, more specifically the FLIR ONE, could have a significant role in classifying burn wound healing time into burns healing in over 21 days if the wound is over 1–1.15 °C cooler than the surrounding normal skin.

One drawback of the FLIR ONE device is demonstrated by the unpaired t-test in Figure 3. For each healing time category, there is a wide range of distribution in the y-axis readings (the difference between the burn injury and normal skin) with an overlap between the two healing time categories. In clinical practice, the FLIR ONE may potentially produce a temperature difference reading that may lead to false-positive or false-negative readings when predicting healing times. When the temperature difference of 1.1 °C between normal skin and burn wound was applied as a predictor of wound healing time, the FLIR demonstrated a sensitivity of 66.67% and specificity of 76.67% in predicting burn healing within three weeks. LDI demonstrated a sensitivity and specificity of 93.33% and 40%, respectively.

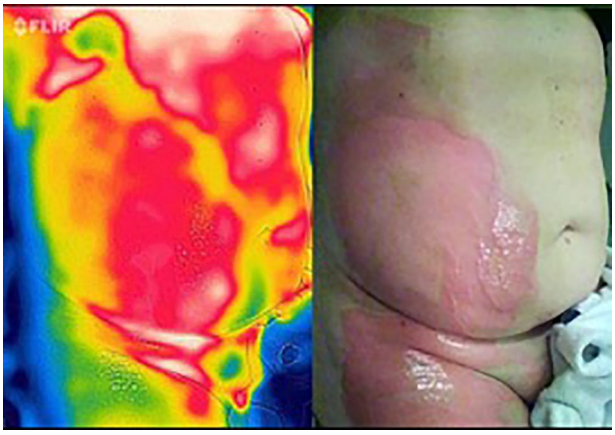

Figure 6. A superficial burn seen in the visual image is shown by the thermographic image taken by the FLIR ONE (on the left) to be a range of temperatures as per the colour palette.

Some images showed a strong temperature correlation to that of the LDI, while others contrasted greatly. It is worth mentioning again the colour palette calibration of the FLIR ONE device: the colour palette of the FLIR ONE images was set so that blue indicated the coldest temperature, followed by green, yellow, red and white indicating the hottest temperature. Figure 5 shows the FLIR ONE image on the left and the Moor LDI image on the right, with a normal photo in the middle.

The warmest region of the injury according to the FLIR ONE corresponds with the area of greatest flux using the MOOR LDI, demonstrating that temperature appears to correlate with the microvascular flow. The images in Figure 6

illustrate that the FLIR one can often show areas of superficial burn wound that appear colder than would be expected. This phenomenon was discovered in several instances and was theorised to be due to evaporative water loss from the burn injury cooling the surface of the wound. This has been found in other studies leading to inaccurate readings.[10] Evaporative water loss has been shown to be three times higher in full-thickness burns compared with superficial type burns,[13] which evidently can lead to the overprediction of healing time as these burns would appear cooler relative to normal skin.

Before using the FLIR Tools mobile software, the burn wound spot temperature measurements were taken from the FLIR ONE mobile application. The standard FLIR ONE mobile application allows for a thermographic image to be taken with on the spot temperature assessment. However, the FLIR Tools app software allows for more accurate mean temperature analysis compared to the FLIR ONE mobile application. The FLIR Tools app is a separate app that can be installed on the mobile, tablet or a laptop/computer. In the clinical setting, the instantaneous nature of the FLIR ONE has a somewhat diminished appeal if the FLIR Tools software needs to be used for more accuracy as images need to be imported and adequately reviewed by the user. The temperature assessment of the FLIR ONE mobile device would be improved if it allowed instantaneous mapping of the burn wound and calculated an average temperature, while simultaneously providing an estimate of burn wound healing times by comparing it to the temperature of normal skin. Such a software update would make its use far more practical and useful in the clinical setting.

Conclusion

While the FLIR ONE certainly has its drawbacks, it is a low-cost, portable device and offers the ability to take instant images with spot temperature measurements. This study has shown the FLIR ONE to achieve a sensitivity of 66.67% (95% CI = 52.71–89.86) and specificity of 76.67% (95% CI = 12.52–85.51) when predicting a burn injury would heal within 21 days. This research has also shown with statistical significance ($P < 0.05$) that the FLIR ONE shows that burns healing in less than 21 days have a mean temperature difference (when compared with normal skin) of approximately 1 °C compared with burns healing in over 21 days. This mean temperature difference is similar to that found in the literature[12] for burns healing in less than 21 days compared with burns healing in over 21 days. This research was also able to show that there is a statistically significant correlation between the temperature difference between a burn injury and normal skin – the higher the difference between the two temperatures, the longer the healing time. These results show great promise in the use of the FLIR ONE as a clinical aid in the assessment of burn injuries, but more research is needed to develop the FLIR ONE tool to provide more consistently reliable results. The FLIR ONE is unlikely to rival the MOOR LDI as the NHS 'gold standard', but there is potential for the FLIR ONE to be used in centres where the MOOR LDI's costs and sheer size act as a barrier.

Declaration of conflicting interests

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