Thermometric diagnosis of peripheral nerve injuries

ASSESSMENT OF THE DIAGNOSTIC ACCURACY OF A NEW PRACTICAL TECHNIQUE

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The diagnosis of nerve injury using thermotropic liquid crystal temperature strips was compared blindly and prospectively against operative findings in 36 patients requiring surgical exploration for unilateral upper limb lacerations with suspected nerve injury. Thermotropic liquid crystal strips were applied to affected and non-affected segments in both hands in all subjects. A pilot study showed that a simple unilateral laceration without nerve injury results in a cutaneous temperature difference between limbs, but not within each limb. Thus, for detection of a nerve injury, comparison was made against the unaffected nerve distribution in the same hand.

Receiver operating characteristic curve analysis showed that an absolute temperature difference ≥1.0°C was diagnostic of a nerve injury (area under the curve = 0.985, sensitivity = 100%, specificity = 93.8%).

Thermotropic liquid crystal strip assessment is a new, reliable and objective method for the diagnosis of traumatic peripheral nerve injuries. If implemented in the acute setting, it could improve the reliability of clinical assessment and reduce the number of negative surgical explorations.

Injuries to the hand and forearm are present in 20% of patients attending emergency departments.1-3 Most are traumatic lacerations,3,4 which are often underestimated on clinical examination. A low threshold for surgical exploration is therefore warranted to ensure that the nerves and tendons are in continuity.2,3,5-7 However, this can lead to unnecessary surgery.2,7

Clinical assessment of a suspected peripheral nerve injury is typically performed using subjective tests. By their nature, these can be unreliable in acutely-injured patients who may be distressed, confused, intoxicated, or even unconscious. Motor assessment can be prevented by pain or other injuries. For sensory evaluation, no test has been acknowledged as absolutely reliable.8,9 Some objective tests have been described, including finger wrinkling and sweat tests.10 However, these are difficult to perform in the acute care setting,11 lack the necessary sensitivity and specificity, and are not reproducible.12-14 The most widely-used test is two-point discrimination. Although this is not entirely subjective, it can be unreliable or difficult to perform in some of the groups of patients mentioned above. Besides, its sensitivity and specificity in detecting acute nerve injuries have not been previously described.

We aimed to introduce a reliable method of objective assessment for suspected peripheral nerve injury by evaluating the effects of sympathetic denervation on the affected cutaneous segment.

Division of a peripheral nerve causes sympathetic denervation within its distribution, resulting in alterations in cutaneous perfusion and temperature.13,15-17 Temperature may be increased or decreased, depending on the number and location of damaged sympathetic fibres.13 Variations in temperature of up to 2.4°C can occur between the cutaneous segment on the injured side and the contralateral normal segment.16 The difference is less than 0.24°C between normal limbs.13,16

This study aimed to assess the diagnostic accuracy of thermotropic liquid crystal temperature strips as a screening tool for suspected peripheral nerve injury by detecting variations of cutaneous temperature. The liquid crystals in the strips can be calibrated to measure the cutaneous temperature in a targeted temperature range. A coloured line is displayed on a temperature scale, indicating the object’s surface temperature (Fig. 1).
Patients and Methods

This was a prospective study performed at a regional hand trauma unit between March and July 2006. All the subjects recruited were divided into three groups. Group 1 included members of staff and patients with no hand or upper limb injuries; group 2 included patients admitted for surgical exploration of lacerations in the upper limb, but with no clinical suspicion of nerve injury; group 3 included patients with lacerations in the upper limb admitted for surgical exploration of a suspected peripheral nerve injury, with or without suspected injury to other structures (e.g., tendon).

The presence or absence of nerve injury was determined clinically by junior medical staff, independent of the authors. Exclusion criteria included major vessel injury, a history of peripheral vascular disease or Raynaud’s phenomenon, a previous history of compressive neuropathy or nerve injury, or more than one suspected nerve injury in the same limb. Patients with injuries distal to the level of the proximal interphalangeal joint were also excluded because of lack of space to apply strips. A total of 40 subjects each in groups 1 and 2, and 36 in group 3, were included in the study. The demographic data and the level of injury are shown in Table I.
A pilot study involving groups 1 and 2 was conducted to study the temperature changes within an injured limb that occur independently of the effects of denervation. The aim was to identify a potential source of major bias in the main study (group 3). The temperature was compared between the area supplied by the median and the ulnar nerve within each hand, and between the corresponding median and ulnar nerve territories in the contralateral hand.

In the main study (group 3), a comparison was made between the affected (area IA) and the unaffected (area IU) in the injured hand and the similar areas in the contralateral hand (areas CA and CU). The precise areas relied on the territory and the level of the suspected nerve injury. Area IA was in the territory of the suspected injured nerve and area IU was in the territory of a clinically intact nerve on the same surface (palmar or dorsal) of the hand. An example is shown in Figure 2. In suspected radial nerve injuries the thermotropic liquid crystal strips were placed on the radial and ulnar sides of the dorsum of the hand. For suspected median or ulnar nerve injuries, the strips were placed on the thenar and hypothenar eminences if the injury was in the proximal two-thirds of the forearm and the dressing was not covering the palm. Otherwise, the strips were applied to the palmar surface of the corresponding autonomous digit, i.e. the index for the median and the little finger for the ulnar nerve. For distal lacerations, the strips were placed on the autonomous corresponding digit or the distribution corresponding to the suspected digital nerve (Fig. 3).
Table II. Temperature differences in groups 1 and 2

<table>
<thead>
<tr>
<th>Temperature difference</th>
<th>Signed temperature difference (°C)</th>
<th>Absolute temperature difference (°C)</th>
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<tbody>
<tr>
<td></td>
<td>Range*</td>
<td>Mean</td>
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<tr>
<td>Group 1</td>
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<tr>
<td>Temperature difference</td>
<td></td>
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<tr>
<td>Right within hand</td>
<td>-0.5 to 0.5</td>
<td>0.0 to 0.5</td>
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<tr>
<td>Left within hand</td>
<td>-0.5 to 0.5</td>
<td>0.0 to 0.5</td>
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<tr>
<td>Median between hands</td>
<td>-0.5 to 0.5</td>
<td>0.0 to 0.5</td>
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<tr>
<td>Ulnar between hands</td>
<td>-0.5 to 0.5</td>
<td>0.0 to 0.5</td>
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<tr>
<td>Group 2</td>
<td></td>
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<tr>
<td>Temperature difference</td>
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<td></td>
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<tr>
<td>Within injured hand</td>
<td>-0.5 to 0.5</td>
<td>0.0 to 0.5</td>
</tr>
<tr>
<td>Within uninjured hand</td>
<td>-0.5 to 0.5</td>
<td>0.0 to 0.5</td>
</tr>
<tr>
<td>Median between hands</td>
<td>-1.5 to 2.5</td>
<td>0.5 to 1.0</td>
</tr>
<tr>
<td>Ulnar between hands</td>
<td>-2.0 to 2.0</td>
<td>0.5 to 1.0</td>
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* ranges also apply to the mean values
† 95% CI, 95% confidence interval

Temperature was assessed by trained junior medical staff, independent of the authors, who were blinded to the outcome of the surgical exploration and clinical examination. A detailed explanation of the procedure was given to the subjects and informed consent was obtained. Patients from groups 2 and 3 were assessed pre-operatively on the day they attended for surgical exploration. No attempt was made to control environmental temperature, so as to simulate conditions of clinical assessment in a busy emergency department. Commercially available thermotropic liquid crystal temperature strips were used (Hallcrest Inc., Derby, United Kingdom). We used L-314 Moving Line Forehead Thermometer strips (Hallcrest Inc.) for measurements in the palm, and L-308 Perfusion Monitor strips (Hallcrest Inc.) in the digits (Fig. 1). For each strip, the reading was taken at the upper boundary that separates the coloured indicator line from the colourless (black) zone beyond. This reading was recorded as the temperature indicated by the indicator line from the colourless (black) zone beyond. None of the patients in group 2 had nerve injuries on surgical exploration, which is in line with clinical suspicion.

Results

Pilot study. Table II summarises the differences in temperature between different areas. Group 1 subjects showed similar temperature readings in all four areas. Group 2 patients showed similar temperatures within each hand, but comparison of the temperature between the injured and the uninjured hand showed a significant difference for both the median and the ulnar nerve territories (Wilcoxon's signed ranks test; median nerve: p = 0.0274; ulnar nerve: p = 0.0243). The median difference in temperatures suggested that the injured side was warmer by 0.5°C for both nerves (95% CI 0°C to 0.5°C for both. Means 0.38°C, 0.35°C). None of the patients in group 2 had nerve injuries on surgical exploration, which is in line with clinical suspicion.

Main study. In group 3, on surgical exploration, 20 of the 36 patients (55.6%) were found to have partial or complete nerve divisions. Six median, four ulnar, two superficial radial and eight digital nerves were injured. Five of 20 patients (25%) had partial nerve injury: three median (estimated percentages of lacerations 80%, 70% and 10%), one ulnar (75%), and one ulnar digital nerve of the middle finger (40%). Eight patients with nerve injury, and four patients with no nerve injury, had associated tendon lacerations. No patient had more than one nerve injury. Of the 16 limbs without a surgically identifiable nerve
injury, 15 (93.8%) demonstrated a difference of \( \leq 0.5^\circ \text{C} \) within the same hand; one (6.3%) patient had a difference of 1.0°C. All 20 limbs with nerve injuries had a difference of 1.0°C or more within the affected hand. Of these, 15 (75%) had increased temperature in the territory of the damaged nerve, and five (25%) had a reduced temperature. There was no relationship between the degree of partial nerve injury and the rise or fall in temperature. In view of this variation in the direction of temperature change, analysis was performed on the absolute temperature difference rather than on the signed difference. The results are summarised in Table III. In the limbs without nerve injury, the median absolute temperature difference within hands was 0.0°C (mean 0.19°C, 0.09°C) whether in the injured or contralateral side. However, in limbs with surgically confirmed nerve injury the median absolute temperature difference within the affected hand was 1.25°C (mean 1.38°C). The absolute differences within the affected hand were significantly greater than the differences within the contralateral hand (Wilcoxon’s signed rank test, \( p < 0.0001 \)). In contrast, the differences did not show statistically significant dissimilarity in patients with no nerve injury (Wilcoxon’s signed rank test, \( p = 0.25 \)). The median absolute temperature difference between the affected area (IA) and the corresponding contralateral territory (CA) was 2.0°C (mean 2.3°C). However, in line with the findings from group 2, there was also an absolute temperature difference between sides in the unaffected territories (median difference 1.0°C (mean 1.6°C) in nerve-injured patients and 0.75°C (mean 0.69°C) in patients with intact nerves).

Receiver operating characteristic curve analysis showed that a temperature difference of 1.0°C or more
between the affected and unaffected area (areas IA and IU) in the injured hand is consistent with nerve injury (Fig. 4). Applying the same technique to the comparison of injured and uninjured hands (areas IA and CA) supported a cut-off point of 1.5°C or more.

In group 3, static two-point discrimination was normal in 11 patients with an intact nerve, and in one patient with surgically proven nerve laceration. Abnormal two-point discrimination was found in 19 patients with injured nerves and in five with intact nerves, based on the results of surgical exploration. Although two-point discrimination was not a formal part of the study, its sensitivity and specificity were 95% (78.2% to 100) and 68.8% (41.3% to 89.0%), respectively.

### Discussion

This study aimed to introduce a new objective method of screening for the detection of peripheral nerve injuries in the upper limb. It is based on the principle of the alteration of cutaneous temperature that occurs in injuries of the nerve. This concept is not new, and techniques such as laser Doppler fluxmetry, liquid crystal thermography, and computerised colour telethermography have been used in the past. However, these tools are expensive and the techniques complicated, which renders them less useful in the acute setting.

Our study shows a statistically significant effect of nerve injury on the difference in temperature between the affected and unaffected areas. Such an effect could not be detected in the injured hand where there was no underlying injury of the nerve. Receiver operating characteristic curve analysis supports the selection of ≥ 1.0°C as a cut-off in the injured hand, which maximises the sensitivity and specificity of temperature difference for the detection of nerve injury. The area under the receiver operating characteristic curve provides an estimate of the power of the test to discriminate the presence or absence of nerve injury (diagnostic accuracy). The area under the curve for temperature differences measured on the injured side was greater than that for differences between the two sides. This strongly suggests that in clinical practice a comparison should be made with an area corresponding to a non-affected nerve within the same hand, rather than the corresponding area on the opposite hand.

Our pilot study demonstrated that in the absence of a nerve injury there is no significant temperature difference between two separate nerve distributions within the same hand, even in the presence of a recent injury to the same limb. However, we have demonstrated that the presence of a unilateral laceration, without underlying nerve injury, can cause a clear temperature difference between the injured and the uninjured limb. We are unable to explain this difference, but it is independent of nerve injury and might be related to injury-induced changes in blood flow or the presence of dressings. This difference in temperature in an injured limb introduces an additional source of variation which may explain the poorer discrimination of the technique when comparison was made between corresponding areas in the injured and uninjured hands rather than within the injured hand.

A previous study has shown that sympathetic changes could be detected four minutes after the injection of local anaesthetic. In our study, the time to assessment varied from between the day of the injury and 13 days later. Sympathetic changes in a nerve injury can last for between five and eight months. Therefore, we believe that our method is applicable for both acute and late assessment.

All the patients with a nerve injury had a temperature difference of 1.0°C or more, but the direction of this was inconsistent, albeit predominantly warmer on the affected side. Peripheral nerve injury causes either an increased or a decreased temperature in its territory. Injuries with complete interruption of all the sympathetic fibres result in areas of increased temperature because of loss of sympathetic outflow, whereas injuries with partial sympathetic nerve interruption result in areas of increased and decreased temperature secondary to the pathologically overactive state of the intact sympathetic nerves. This perhaps explains why some patients with nerve injury showed an increase in temperature whereas others showed a decrease. However, we acknowledge that this does not offer the entire explanation, as some patients with complete injuries had a reduced temperature. The mechanism of temperature changes in a peripheral nerve injury is far more
complex. Various mechanisms underlying temperature changes in nerve injuries include anatomical variations and the complexity of thermotopic liquid crystal strip assessment against a background of a strongly suggestive clinical assessment until similar studies on a larger scale have been performed. The thermotropic liquid crystal temperature strips were difficult to apply in injuries distal to the proximal interphalangeal joint because of lack of space. This is a potential drawback of the technique, but reduction in size is technically possible and should allow assessment of more distal injuries. Also, the presence of multiple nerve lesions may not permit comparison of temperatures in the same hand if there is no unaected area on the same surface of the hand. The performance of the temperature strips test between hands, albeit inferior to within-hand discrimination, is still satisfactory and could be used in this situation.

In group 3, 16 of 36 (44.4%) patients had no nerve injury on surgical exploration. If static two-point discrimination had been used as a diagnostic test, only five patients would have been falsely diagnosed with a nerve injury, but one injury would have been missed. However, using the temperature strips, nerve injury would have been excluded in 15 of those 16 patients, and no injury would have been missed. Therefore, the use of thermotropic liquid crystal temperature strips in the assessment of the acute hand injury may safely reduce the number of patients referred to specialist hand services for exploration of suspected nerve injuries, provided no other structures are involved.

This study demonstrates that thermotropic liquid crystal temperature strips can detect peripheral nerve injuries in patients with traumatic upper limb lacerations when a temperature difference of 1.0°C or more exists between the territory of the affected nerve and an unaected area on the same hand. The technique is accurate, and could help minimise the number of patients with negative surgical explorations for suspected nerve injury by improving the reliability of clinical assessment. It is an objective method which is cheap, easy to use, and can reliably be performed in the acute setting without the need to remove dressings.

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References