Skin temperature measured by infrared thermography after specific ultrasound-guided blocking of the musculocutaneous, radial, ulnar, and median nerves in the upper extremity

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Editor’s key points

- Infrared thermography was used to map skin temperature after specific nerves were blocked in the upper arm.
- Musculocutaneous, radial, median, or ulnar nerves were blocked under ultrasonographic guidance.
- Block of ulnar and median nerves, but not the others, resulted in a significant increase in temperature.
- The study adds to the knowledge regarding accurate effects of blocking individual nerves.

Background. Sympathetic block causes vasodilatation and increases in skin temperature (Tw). However, the Tw response after specific nerve blocking is unknown. In this study, we hypothesized that Tw would increase after specific blocking of the nerve innervating that area.

Methods. Forty-six patients undergoing hand surgery were included. We performed ultrasound-guided, specific nerve blocking of either the musculocutaneous, radial, ulnar, or median nerve in each patient and analysed Tw in the forearm and hand at 2 min intervals in the following 22 min by the use of infrared thermography. Areas of interest corresponding to the cutaneous innervation area of each of the four nerves were defined and the mean Tw in each area was analysed.

Results. Specific blocking of the ulnar and median nerves caused a substantial increase in mean (sd) Tw in the areas innervated by these nerves [5.2 (3.2)°C and 5.1 (2.5)°C, respectively; both P<0.0001]. The increase was even larger at the fingertips. Median nerve blocking also increased Tw in the area of the hand innervated by the radial nerve (P<0.0001). However, Tw did not increase in any area after either musculocutaneous or radial nerve blocking.

Conclusions. Specific blocking of the ulnar and median nerve causes substantial increases in Tw in specific areas of the hand. In contrast, the specific blocking of the musculocutaneous or radial nerve does not increase Tw. Further studies are needed to clarify if these findings can be used to objectively evaluate brachial plexus block success.

Keywords: anaesthetics, local; peripheral nerves; skin temperature; sympathetic nervous system; thermography.

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Peripheral nerve blocks are widely used in regional anaesthesia. However, it can be difficult to evaluate block success, because existing methods rely on subjective testing (pinprick, cold/warm stimulation, etc.) and, clearly, there is a need for an objective method.1 2

Sympathetic blocking leads to vasodilatation, increased blood flow, and, hence, an increase in tissue/skin temperature.3–5 Since sympathetic fibres are contained in peripheral nerves, recent studies have investigated whether increases in Tw can be used to evaluate and predict brachial plexus block success.6–8 Although they all demonstrated increases in Tw, they did not agree on the usefulness of Tw to predict and evaluate block success. However, the studies were performed proximally in the brachial plexus, where the nerves intermingle, divide, and lie very close to each other, and therefore we do not know the thermal response to the blocking of specific peripheral nerves. Is there indeed a thermal response after a specific peripheral nerve is blocked? This knowledge lacks, but seems essential for interpreting the results from previous studies and for designing future clinical studies that investigate the usefulness of changes in Tw to evaluate and predict peripheral nerve block success.

Today, it has become possible to visualize and block peripheral nerves by the use of ultrasonographic guidance.9 In the present four separate physiological studies, we measured Tw in the upper extremity after performing specific, ultrasound-guided nerve blocks of the musculocutaneous, radial, ulnar, and median nerves, respectively. We hypothesized that the blocking of a specific nerve would lead to increased Tw in the area innervated by that nerve. In addition, we used infrared thermographic imaging, which provides a two-dimensional thermal image with a
thermal resolution $<0.07^\circ C$ as opposed to single point measurements.

**Methods**

The Committees on Biomedical Research Ethics of the Capital Region of Denmark approved the study protocol (protocol nr. H-C-2008-047) in accordance with the declaration of Helsinki.

Forty-six patients, ASA I–III were included; median (range) age 57 (22–83) yr, height 168 (154–193) cm, weight 66 (51–101) kg, BMI 23.5 (18.5–37.6) kg m$^{-2}$, and ASA I (I–III). Before inclusion, all patients gave written informed consent. Exclusion criteria were: age $<18$ yr, international normalized ratio $>1.4$, platelet count $<80 \times 10^9$ litre$^{-1}$, coagulopathy, medication with vitamin K-antagonist/high-dose heparin or fractionated heparins, allergy to local anaesthetics, infection

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**Fig 1** AOIs in the forearm and hand. Circular light blue areas on the second and fifth digit depict $T_{\text{Spot}}$. (a) Prone (dorsal) position; (b) supine (palmar) position.
formed a specific nerve block in the following way: Inc., Bothell, WA, USA), we identified the nerve and per-
sterile transparent drape over the planned injection site. To ensure that the local anaesthetic was dis-
nerve stimulator (Stimuplex G 35 mm, 15 w)
visible contraction of the biceps brachii muscle in response
to the nerve. If in doubt, we confirmed nerve identity by
2–3 electric impulses (2 Hz, 1.5 mA, 0.1 ms) with a
electric impulse generator (Stimuplex R HNS 12 Peripheral Nerve Stimulator, B.Braun Melsungen AG). We then injected 6
ml ropivacaine 7.5 mg ml
w
X 240 pixels. Because the emissive factor of the skin is
320
×
889

<table>
<thead>
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<th>Nerve block</th>
<th>Median</th>
<th>Musculocutaneous</th>
<th>Radial</th>
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<td>Age (yr)</td>
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<td>62 (42–77)</td>
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<td>Height (cm)</td>
<td>172 (158–193)</td>
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<tr>
<td>Weight (kg)</td>
<td>69 (51–96)</td>
<td>68 (57–83)</td>
<td>70 (60–86)</td>
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| BMI (kg m
2
)    | 23.7 (19.4–27.2) | 24.6 (20.3–30.1) | 24.3 (22.3–30.5) |
| ASA                 | 1.0 (1–2) | 1.0 (1–2) | 1.0 (1–3) |
| Acute/elective      | 2/12   | 2/5              | 1/6    |

All the blocks were performed by two dedicated investigators.

**Infrared thermographic imaging**

Immediately after perineural anaesthetic injection, we started infrared thermographic imaging of the forearm and hand (baseline) and saved images at 1 min intervals during the following 22 min (Thermovision A320, FLIR Systems, Dan-
deryd, Sweden). The camera was newly calibrated and fixed in a standardized position ~1.30 m vertically above the bed. Thermovision A320 has a thermal resolution of <0.07°C, an accuracy of ±2%, and a picture resolution of 320×240 pixels. Because the emissive factor of the skin is 0.98, the measured temperature values can be evaluated as skin temperature values. Infrared imaging was performed with the radial forearm facing the infrared camera after mus-
culocutaneous nerve blocking (n=7) and with the forearm in the prone position after radial nerve blocking (n=7). Since the ulnar and the median nerves innervate both the dorsal and palmar sides of the skin in the hand and because it is important not to move or manipulate the hand during thermographic imaging, 14 patients were included after specific median and ulnar nerve blocking. This allowed thermo-
graphic imaging of the dorsal hand in seven patients and of the palmar hand in seven patients in each of these two groups. No interventions were performed during infrared imaging, and the patients were instructed not to move forearm/hand during the measurement period.

**Block assessment**

We assessed sensory function of the blocked nerve 22 min after performing the block according to the innervation areas as shown in Figure 1. Cold sensation was assessed by applying a cooled object (5°C) over the innervated skin with
Table 2  Mean skin temperature ($T_s$) at baseline (0 min) and at 6, 10, and 22 min after performing a specific peripheral nerve block. Values are means (SD) and (range). The increase was calculated as $T_s$ at 22 min minus $T_s$ at 0 min. Ref, reference area; AOI, area of interest; Spot 2nd, circular area on second finger (Fig. 1A and B); Spot 5th, circular area on fifth finger (Fig. 1A and B). Median and ulnar nerve values are pooled data from the dorsal and palmar groups except AOI Rad, which only includes the dorsal group. Included in AOI of the median nerve is AOI of the radial nerve (AOI Rad). P-values obtained with a repeated-measures general linear model; in the case of violation of sphericity, the Greenhouse–Geisser P-values are presented (see text for further details). *$P<0.05$. **$P<0.01$ [compared with 0 min (after the Bonferroni correction)]. $^aP<0.0001$ when comparing temperature increase between the wrist and tip with an independent t-test. $^bP<0.05$ when comparing temperature increase between the dorsal and palmar sides of the hand with an independent t-test.

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<td></td>
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<td>6 min</td>
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<td>32.1 (3.4)$^a$$^b$</td>
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<td>31.9 (2.8)$^a$</td>
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<td>Tip</td>
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<td>34.4 (1.4)$^a$$^b$</td>
<td>35.4 (0.8)$^a$$^b$</td>
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from the thermographic images that the greatest increase in $T_s$ occurred in the fingertips. We therefore performed spot measurements ($T_{\text{spot}}$) on the pulpa (palmar hand view) and just proximal to the nail bed (dorsal hand view) on the second and fifth finger after specific ulnar and median nerve blocking (Fig. 1A and B). Each spot measured $\sim$0.75 cm$^2$ and $T_{\text{spot}}$ was measured as the average $T_s$ in that area. We also measured average $T_s$ in small areas at the fingertips ($\sim$0.5 cm$^2$) and at larger areas ($\sim$2–4 cm$^2$) at the wrist after specific ulnar and median nerve blocking.

**Statistical analysis**

Before the study, we estimated $n$ to five by setting $\Delta T_s$ to 2°C, estimating the SD to 0.8°C, and choosing the power to 0.8 and $\alpha$ to 0.05 (two-sided). Since both the median and ulnar nerve study comprised a palmar and a dorsal view group, we included 42 patients in six groups. We performed statistical analyses with an SPSS software package (SPSS, version 17.0 for Windows$^\text{®}$, SPSS, Chicago, IL, USA). To analyse changes in $T_s$ during the experiments, we applied a repeated-measures ANOVA. At first, Mauchly’s test of sphericity was assessed. If the assumption about sphericity was violated, the degrees of freedom were corrected using the Greenhouse–Geisser estimates of sphericity. Included in the model was $T_s$ at time $t=0$, 6, 10, and 22 min. All calculations were done separately for $T_s$AOI, $T_{\text{spot}}$, and $T_{\text{ref}}$ for each specific nerve block. Comparisons between $T_s$ at the different time points are reported after the Bonferroni correction. The increases in $T_s$ measured at the fingertips and the wrist were

**Fig 2** Mean skin temperature in the AOIs ($T_s$AOI) at baseline and at 2 min intervals after performing the specific musculocutaneous, radial, ulnar, or median nerve blocks. Included in the median nerve AOI is the AOI innervated by the radial nerve on the dorsal hand (Fig. 1A). Values are means (SEM). $P$-values obtained by a repeated-measures ANOVA, including the values at $t=0$, 6, 10, and 22 min. $n=7$ in the musculocutaneous and radial nerve groups. $n=14$ in the median and ulnar nerve groups (both seven dorsal and seven palmar measurements).
The specific blocking of the ulnar nerve resulted in a substantial and significant increase in $T_s$ in the area innervated by the ulnar nerve in the dorsal, palmar, and pooled (dorsal + palmar) groups (all $P<0.001$; Table 2, Figs 2 and 3). $T_s$AOI in the pooled group increased by mean (range) 5.2 (1.4–10.7) °C from baseline to 22 min, and $T_{spot}$ of the fifth finger increased by 7.5 (1.8–13.4) (both $P<0.0001$). $T_{s,ref}$ did not increase ($P=0.36$; Table 2).

Similarly, the specific blocking of the median nerve resulted in a marked and significant increase in $T_s$ in the area innervated by the median nerve in the dorsal, palmar, and pooled groups (all $P<0.001$; Table 2, Figs 2 and 4). In the analysis of the dorsal and pooled groups, we chose to include the area innervated by the radial nerve (AOI Rad), because it seemed that $T_s$ also increased in this area after specific blocking of the median nerve. Including this area leads to a minor underestimation of the increase in $T_s$AOI after median nerve block, whereas excluding this area would lead to an overestimation of $T_s$AOI in the pooled group because of large differences in the size of the areas between the dorsal (fingertips) and palmar (most of the palmar area) groups. $T_s$AOI in the pooled group increased by 5.1 (1.7–10.4) °C from baseline to 22 min and $T_{spot}$ of the second finger increased by 8.4 (1.4–12.0) °C (both $P<0.0001$). Median nerve block also resulted in a significant increase in the area innervated by the radial nerve (AOI Rad; $P=0.004$, Table 2) and $T_{s,ref}$ increased slightly by 0.7 (−0.7 to 2.5) °C ($P=0.003$; Table 2).

$T_s$ increased more on the palmar side than on the dorsal side after specific median and ulnar nerve blocking (both groups pooled; $P<0.05$, Table 2 and Fig. 5) and the increase in $T_s$ was more pronounced in the fingertips compared with the wrist (both groups pooled; $P<0.0001$, Table 2 and Fig. 5).

In contrast, no increase in $T_s$ in any area of the forearm or hand was observed after performing specific musculocutaneous or specific radial nerve blocks (Table 2 and Fig. 2).

**Discussion**

In this study, we hypothesized that the blocking of specific peripheral nerves in the upper extremity would cause increased $T_s$ in the areas innervated by these nerves. The specific ulnar and median nerve blocks resulted in a substantial increase in $T_s$ in the areas innervated by these nerves ($\approx 5$ °C). Furthermore, the specific median nerve block resulted in a substantial increase in $T_s$ in the dorsal hand area innervated by the radial nerve. However, the specific blocking of the musculocutaneous or the radial nerve did not increase $T_s$ in any area. The largest increase in $T_s$ occurred in the fingertips ($\approx 8$ °C). These findings are new and contrast our hypothesis that the blocking of a specific peripheral nerve always leads to increases in $T_s$ in the areas innervated by that nerve.

No previous studies have investigated the thermographic response after specific peripheral nerve blocking and only a few studies have investigated $T_s$ after brachial plexus block at different anatomical levels. Interscalene brachial plexus block resulted in increased $T_s$ in the areas innervated by...
the radial, ulnar, and median nerves but not in the areas innervated by the musculocutaneous or axillary nerves. Both infraclavicular and axillary brachial plexus blocks resulted in increased $T_s$ in the anaesthetized dermatomes. However, our data show that a combined median and ulnar nerve block will cause a substantial increase in $T_s$ in all areas of the hand (and wrist) with the largest increase located in the fingertips. We therefore believe that the increases in $T_s$ found after brachial plexus blocks at different levels in the previous studies simply reflect successful

Fig 4 Typical infrared thermographic images of the hand in the prone position after performing the specific median nerve block. (a) Baseline, (b) 4 min, (c) 5 min, (d) 6 min, (e) 7 min, and (f) 22 min after performing the block. The skin temperature initially increases at the fingertips and extends proximally along the veins.

Fig 5 Mean skin temperature after specific ulnar and median nerve blocking. Pooled data from both groups. Measurements performed at the fingertips (tips), at the wrist, and the dorsal and palmar AOI of each nerve (Fig. 1). Included in the data after median nerve block are data from areas innervated by the radial nerve on the dorsal side of the hand (Fig. 1A). Values are means (SEM). $P$-values obtained by a repeated-measures ANOVA, including the values at $t=0, 6, 10,$ and $22$ min. $n=14$ in the palmar and dorsal groups, $n=28$ in the wrist and tip groups.
median and ulnar nerve block as part of the brachial plexus block.

We defined the AOIs according to Figure 1 and obviously digit 4 represents an overlying area between the cutaneous innervation areas of the median and ulnar nerves. With respect to the fourth digit, only the ulnar half was included in the AOI after ulnar nerve block and only the radial half was included after median nerve block. However, in almost all patients, ulnar nerve block led to a substantial increase in TR of the radial half of the fourth digit (Fig. 3) and median nerve block resulted in a similar increase in TR of the ulnar half of the fourth digit (Fig. 4).

The mechanisms behind the substantial increase in TR after specific blocking of the median and ulnar nerves are not known in detail. It seems that the first response is an increase in TR in the fingertips (Fig. 4). This may be explained by the opening of arteriovenous anastomoses in the fingers caused by the blocking of specific sympathetic nerve fibres.15 Apparently, these fibres are only present in the median and ulnar nerves. Subsequently, the increased blood flow in the fingertips dilates nearby veins and TR increases proximally and laterally along these veins, initially causing a very inhomogeneous TR distribution (Figs 3–5). We therefore speculate that the changes in TR proximal to the fingertips are only secondary as a consequence of this phenomenon. This explanation is in agreement with previous findings in the lower extremity.16 However, further studies are needed to clarify whether this is a valid explanation and how the differences between the dorsal and palmar sides can be explained (Fig. 5).

Baseline temperatures of the areas innervated by the musculocutaneous and the radial nerves were higher than those of the areas innervated by the ulnar and median nerves (Fig. 2). In our opinion, this simply reflects that TR increases when measuring closer to the body core and when the fingers/fingertips are not included in the measurements.

Most of the patients included in the study were undergoing elective hand surgery, but a few patients also had fractures/inflammation. It is well known that inflammation can cause increases in TR. Therefore, some patients already had elevated TR at baseline, which would make the detection of an increase in TR more difficult. Consequently, we may have overlooked an increase in TR after performing the specific musculocutaneous and radial nerve blocks. However, given the very high precision of the infrared camera, we do not think that this represents a major weakness of the study. If such changes exist, they are likely to be so small and variable that they are of no clinical interest.

We only measured TR for 22 min after performing the nerve blocks. However, we ensured that each nerve was completely surrounded by local anaesthetic, and since the increase in TR was rapid in onset after both the median and ulnar nerve blocks, we do not think that the lack of an increase in TR after either musculocutaneous or radial nerve block is caused by a too short period of measurements.

The radial nerve was blocked after it emerges from the spiral groove on the humerus. At this site, the nerve has already branched off cutaneous nerves to the forearm. These branches were not consistently anaesthetized in the present study, and we can therefore not exclude that a more proximal radial nerve block would have led to an increase in TR in these areas of the forearm.

The data from the present study show that the thermographic response to the blocking of specific peripheral nerves is different from expected. The input from the sympathetic nervous system is complex and how this influences the thermographic response after brachial plexus at different anatomical levels is not fully understood. Future clinical studies should address whether the knowledge gained in the present study can be used to objectively predict and evaluate brachial plexus block success or failure.

In summary, the specific blocking of the ulnar and median nerves leads to a substantial increase in TR in the areas innervated by these nerves and the increase is even larger in the fingertips. Furthermore, the specific blocking of the median nerve results in increases in TR in the dorsal hand area innervated by the radial nerve. However, the specific blocking of the musculocutaneous or the radial nerve does not increase TR in any area. These results contrast the hypothesis that the blocking of a specific nerve always leads to increases in TR in the areas innervated by the blocked nerve.

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Conflict of interest
None declared.

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