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 ($T_s$). However, the $T_s$ response after specific nerve blocking is unknown. In this study, we hypothesized that $T_s$ 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 $T_s$ 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 $T_s$ in each area was analysed.

Results. Specific blocking of the ulnar and median nerves caused a substantial increase in mean ($\pm$) $T_s$ 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 $T_s$ in the area of the hand innervated by the radial nerve ($P<0.0001$). However, $T_s$ 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 $T_s$ in specific areas of the hand. In contrast, the specific blocking of the musculocutaneous or radial nerve does not increase $T_s$. 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 $T_s$ can be used to evaluate and predict brachial plexus block success.6–8 Although they all demonstrated increases in $T_s$, they did not agree on the usefulness of $T_s$ to predict and evaluate block success. However, the studies were performed proximally in the brachial plexus, where the nerves intermingled, 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 $T_s$ 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 $T_s$ 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 $T_s$ 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°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 × 10$^9$ litre$^{-1}$, coagulopathy, medication with vitamin K-antagonist/high-dose heparin or fractionated heparins, allergy to local anaesthetics, infection

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:

With the use of a high-frequency linear ultrasound transducer (HFL 38 × 13-6 MHz, S-ICUTM Ultrasound System, SonoSite Inc., Bothell, WA, USA), we identified the nerve and perineural anaesthesia. With the ultrasound, we ensured that the local anaesthetic was distributed circumferentially around the nerve. We assessed sensory function of the blocked nerve 22 min after performing the block according to the innervation area as shown in Figure 1.

Thermovision A320 has a thermal resolution of 0.98, the measured temperature values can be evaluated as skin temperature values. Infrared imaging was performed 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 musculocutaneous 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 thermographic 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 the radial forearm facing the infrared camera after musculocutaneous 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 thermographic 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.

**Table 1** Patient characteristics. Values are given as numbers or median (range)

<table>
<thead>
<tr>
<th>Nerve block</th>
<th>Male/female</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (kg m⁻²)</th>
<th>ASA</th>
<th>Acute/elective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulnar</td>
<td>6/8</td>
<td>54 (22–82)</td>
<td>171 (160–186)</td>
<td>65 (57–101)</td>
<td>22.4 (18.5–37.6)</td>
<td>1.0</td>
<td>3/11</td>
</tr>
<tr>
<td>Median</td>
<td>5/9</td>
<td>61 (22–72)</td>
<td>172 (158–193)</td>
<td>69 (51–96)</td>
<td>23.7 (19.4–27.2)</td>
<td>1.0</td>
<td>2/12</td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>2/5</td>
<td>62 (42–77)</td>
<td>163 (154–183)</td>
<td>68 (57–83)</td>
<td>24.6 (20.3–30.1)</td>
<td>1.0</td>
<td>2/5</td>
</tr>
<tr>
<td>Radial</td>
<td>3/4</td>
<td>54 (47–83)</td>
<td>167 (158–188)</td>
<td>70 (60–86)</td>
<td>24.3 (22.3–30.5)</td>
<td>1.0</td>
<td>1/6</td>
</tr>
</tbody>
</table>

at the site of needle insertion, peripheral neurological disease, or Raynaud’s disease.

The study protocol consisted of four separate studies in which we studied the individual thermographic response after specific blocking of one of the four nerves in the upper extremity (the musculocutaneous, radial, median, and ulnar nerves). We performed the specific nerve block in patients undergoing hand surgery before scheduled brachial plexus anaesthesia.

Each patient lay supine in a hospital bed in the recovery room at a room temperature of 21°C. Direct sunlight and draft was avoided, all bandages/clothing were removed from the forearm/hand, and the patient was allowed to acclimatize for 15 min. We inserted a secure i.v. catheter into a superficial vein of the contralateral hand and performed routine monitoring of the patient (NIAP, continuous ECG, and pulse oximetry). After disinfection with ethanol–chlorhexidine (83% and 0.5%, respectively), we placed a sterile transparent drape over the planned injection site.

Using in-line technique, we inserted either a 35 or 50 mm insulated nerve stimulation needle (Stimuplex® D 25 G 35 mm, 15° or Stimuplex® D 22 G 50 mm, 15°; B.Braun Melsungen AG, Germany) and placed the needle tip close to the nerve. If in doubt, we confirmed nerve identity by visible contraction of the biceps brachii muscle in response to 2–3 electric impulses (2 Hz, 1.5 mA, 0.1 ms) with a nerve stimulator (Stimuplex® HNS 12 Peripheral Nerve Stimulator, B.Braun Melsungen AG). We then injected 6 ml ropivacaine 7.5 mg ml⁻¹ (Naropin® 7.5 mg ml⁻¹, Astrazeneca A/S, Albertslund, Denmark) perineurally. With ultrasound, we ensured that the local anaesthetic was distributed circumferentially around the nerve.

**Study 1:** We identified the musculocutaneous nerve in the axillary region as a typical hyper-echoic nerve structure running between the short head of the biceps brachii and the coracobrachial muscle. Using in-line technique, we inserted either a 35 or 50 mm insulated nerve stimulation needle (Stimuplex® D 25 G 35 mm, 15° or Stimuplex® D 22 G 50 mm, 15°; B.Braun Melsungen AG, Germany) and placed the needle tip close to the nerve. If in doubt, we confirmed nerve identity by visible contraction of the biceps brachii muscle in response to 2–3 electric impulses (2 Hz, 1.5 mA, 0.1 ms) with a nerve stimulator (Stimuplex® HNS 12 Peripheral Nerve Stimulator, B.Braun Melsungen AG). We then injected 6 ml ropivacaine 7.5 mg ml⁻¹ (Naropin® 7.5 mg ml⁻¹, Astrazeneca A/S, Albertslund, Denmark) perineurally. With ultrasound, we ensured that the local anaesthetic was distributed circumferentially around the nerve.

**Study 2:** We identified the radial nerve on the lateral side of the arm ~1.5 cm after it emerges from the spiral groove on the humerus and performed the radial nerve block in a similar way to that described above.

**Study 3:** The ulnar nerve was located ~7 cm distal to the olecranon and the ulnar nerve block was performed as described above.

**Study 4:** The median nerve was seen ~4 cm distal to the midline between the wrist and the cubital fossa on the ventral side of the forearm, and the median nerve block was performed as described above.

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, Danbury, 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 musculocutaneous 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 thermographic 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.
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)]. \( ^{\#}P < 0.0001 \) when comparing temperature increase between the wrist and tip with an independent \( t \)-test. \( ^{\$}P < 0.05 \) when comparing temperature increase between the dorsal and palmar sides of the hand with an independent \( t \)-test.

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Area</th>
<th>( n )</th>
<th>Mean skin temperature (°C)</th>
<th>0 min</th>
<th>6 min</th>
<th>10 min</th>
<th>22 min</th>
<th>Increase (°C)</th>
<th>% increase</th>
<th>Mauchly’s test of sphericity</th>
<th>Sphericity assumed</th>
<th>Greenhouse–Geisser</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulnar</td>
<td>Ref</td>
<td>14</td>
<td></td>
<td>29.9 (3.4)</td>
<td>30.1 (3.6)</td>
<td>30.3 (3.7)</td>
<td>30.5 (4.0)</td>
<td>0.7 (–2.9 to 5.3)</td>
<td>2.3 (–9.3 to 17.8)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AOI</td>
<td>14</td>
<td></td>
<td>29.3 (3.3)</td>
<td>32.1 (3.4)**</td>
<td>33.3 (3.6)**</td>
<td>34.5 (2.3)**</td>
<td>5.2 (1.4 to 10.7)</td>
<td>18.8 (3.8 to 42.5)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spot 2nd</td>
<td>14</td>
<td></td>
<td>28.1 (4.1)</td>
<td>28.2 (4.9)</td>
<td>28.3 (4.9)</td>
<td>28.5 (5.4)</td>
<td>0.4 (–4.5 to 7.4)</td>
<td>1.2 (–15.8 to 26.0)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spot 5th</td>
<td>14</td>
<td></td>
<td>27.9 (3.7)</td>
<td>31.9 (5.3)*</td>
<td>33.3 (4.8)**</td>
<td>35.4 (2.1)**</td>
<td>7.5 (1.8 – 13.4)</td>
<td>28.7 (5.2 – 57.5)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>Ref</td>
<td>14</td>
<td></td>
<td>28.3 (3.3)</td>
<td>28.2 (3.4)</td>
<td>28.3 (3.4)</td>
<td>29.0 (3.2)</td>
<td>0.7 (–0.7 to 2.5)</td>
<td>2.6 (–2.5 to 9.1)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>0.003</td>
<td></td>
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<tr>
<td></td>
<td>AOI</td>
<td>14</td>
<td></td>
<td>29.9 (2.9)</td>
<td>31.9 (2.8)*</td>
<td>33.4 (2.7)**</td>
<td>35.0 (1.5)**</td>
<td>5.1 (1.7 – 10.4)</td>
<td>18.0 (4.9 – 41.6)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
<td></td>
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<tr>
<td></td>
<td>AOI Rad</td>
<td>7</td>
<td></td>
<td>30.5 (3.4)</td>
<td>31.0 (3.8)</td>
<td>32.0 (3.6)</td>
<td>34.1 (2.2)*</td>
<td>3.5 (1.4 – 6.9)</td>
<td>12.2 (4.2 – 24.4)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>0.004</td>
<td></td>
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<tr>
<td></td>
<td>Spot 2nd</td>
<td>14</td>
<td></td>
<td>27.4 (4.1)</td>
<td>31.8 (4.6)**</td>
<td>33.8 (3.6)**</td>
<td>35.8 (0.8)**</td>
<td>8.4 (1.4 – 12.0)</td>
<td>33.0 (3.9 – 54.3)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spot 5th</td>
<td>14</td>
<td></td>
<td>27.2 (3.7)</td>
<td>27.1 (3.9)</td>
<td>27.3 (4.0)</td>
<td>27.6 (3.9)</td>
<td>0.5 (–2.1 to 3.0)</td>
<td>1.8 (–8.1 to 11.2)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Musculocutaneus</td>
<td>Ref</td>
<td>7</td>
<td></td>
<td>33.4 (1.6)</td>
<td>33.0 (1.7)</td>
<td>32.9 (1.8)</td>
<td>32.8 (1.9)</td>
<td>–0.7 (–1.6 to 0.1)</td>
<td>–2.0 (–4.7 to 0.2)</td>
<td>0.06</td>
<td>0.002</td>
<td>–</td>
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<tr>
<td></td>
<td>AOI</td>
<td>7</td>
<td></td>
<td>33.6 (0.6)</td>
<td>33.3 (0.5)</td>
<td>33.4 (0.7)</td>
<td>33.2 (0.8)*</td>
<td>–0.4 (–0.8 to –0.1)</td>
<td>–1.2 (–2.3 to –0.2)</td>
<td>0.27</td>
<td>0.08</td>
<td>–</td>
<td></td>
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<tr>
<td>Radial</td>
<td>Ref</td>
<td>7</td>
<td></td>
<td>31.3 (3.1)</td>
<td>31.1 (3.1)</td>
<td>31.2 (3.3)</td>
<td>31.3 (3.1)</td>
<td>0.0 (–0.8 to 1.3)</td>
<td>0.1 (–2.4 to 3.8)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AOI</td>
<td>7</td>
<td></td>
<td>31.4 (2.7)</td>
<td>31.3 (2.8)</td>
<td>31.4 (2.9)</td>
<td>31.8 (2.8)</td>
<td>0.3 (–0.3 to 1.3)</td>
<td>1.0 (–1.0 to 4.5)</td>
<td>0.08</td>
<td>0.08</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Ulnar and median</td>
<td>Wrist</td>
<td>28</td>
<td></td>
<td>31.2 (2.4)</td>
<td>32.3 (2.4)*</td>
<td>33.3 (2.3)**</td>
<td>34.8 (1.8)**</td>
<td>3.6 (–0.2 to 8.8)*</td>
<td>12.2 (–0.7 to 32.5)*</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>28</td>
<td></td>
<td>27.5 (4.1)</td>
<td>31.7 (4.5)**</td>
<td>33.2 (4.3)**</td>
<td>35.3 (1.9)**</td>
<td>7.9 (1.2 – 14.3)</td>
<td>30.9 (3.5 – 64.1)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
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<tr>
<td></td>
<td>Dorsal</td>
<td>14</td>
<td></td>
<td>30.2 (3.3)</td>
<td>31.4 (3.9)</td>
<td>32.3 (4.0)</td>
<td>34.1 (2.5)**</td>
<td>3.9 (1.4 – 9.1)*</td>
<td>13.7 (3.8 – 34.2)*</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Palmar</td>
<td>14</td>
<td></td>
<td>29.0 (2.8)</td>
<td>32.7 (1.9)**</td>
<td>34.4 (1.4)**</td>
<td>35.4 (0.8)**</td>
<td>6.4 (1.7 – 10.7)</td>
<td>23.1 (5.0 – 42.5)</td>
<td>&lt;0.05</td>
<td>–</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
</tbody>
</table>
the skin on the opposite forearm/hand serving as the control. The sensation was recorded as cold/not cold. Pinprick sensation was assessed using a 22 G needle and compared with the opposite forearm/hand and recorded as sensation or no sensation/numb. Motor function of the blocked nerve was assessed after 22 min and compared with the opposite forearm/hand; motor blockade was assessed by the ability to actively flex at the elbow joint (musculocutaneous nerve), extend the wrist (radial nerve), oppose the first finger (median nerve), or flex the distal interphalangeal joint of the fifth finger (ulnar nerve).

Assessment of temperature

We defined the specific areas of interest (AOIs) according to the cutaneous innervation area of each of the four specific nerves (Fig. 1A and B). We did not include the skin proximal to the wrist after radial nerve blocking, because this area was not consistently anaesthetized by our method (Fig. 1A). The AOIs of the blocked nerve were drawn according to Figure 1A and B for each patient by the use of a specific infrared camera software package (ThermaCAM™ Researcher 2.9 Pro, FLIR Systems) and the mean $T_s$ of the areas of interest ($T_s$AOI) calculated at baseline and at 2 min intervals after performing the block (in total 12 measurements). The mean $T_s$ in an area adjacent to the blocked skin area served as a reference temperature ($T_s$ref). Because it was obvious that the fourth finger represented an overlapping area between the median and ulnar nerve, this finger was excluded from the reference area. It became clear from the thermographic images that the greatest increase in $T_s$ occurred in the fingertips. We therefore performed spot measurements ($T$spot) on the pulp (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 $T$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 $2^\circ \text{C}$, estimating the $\sigma$ to $0.8^\circ \text{C}$, 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®, 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, $T$spot, and $T_s$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
compared with an independent t-test as were the increases in $T_s$ measured on the palmar and dorsal sides of the hand. A two-tailed $P$-value of $<0.05$ was considered statistically significant.

**Results**

Forty-two out of 46 included patients completed the study (Table 1). Thirty-four patients were undergoing elective surgery and eight patients were scheduled acutely because of fractures (four distal radial fractures, three fractures of the fifth metacarpus, and one fracture of the middle third phalanx; Table 1). Two patients were excluded due to radial block failure after 22 min and two patients were excluded because of excessive hand movements during thermographic imaging, which made AOI measurements impossible.

All of the performed blocks in the patients completing the study were specific and successful after 22 min when evaluated by cold stimulation, pin-prick, and motor function.

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). $T_s$ increased 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 ($\sim 5$ °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 ($\sim 8$ °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.\textsuperscript{7} Both infraclavicular and axillary brachial plexus blocks resulted in increased $T_s$ in the anaesthetized dermatomes.\textsuperscript{6,8} 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

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig4.png}
\caption{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.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig5.png}
\caption{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 $t=0, 6, 10, \text{and} 22 \text{min.} n=14$ in the palmar and dorsal groups, $n=28$ in the wrist and tip groups.}
\end{figure}
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 overlapping 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 $T_s$ of the radial half of the fourth digit (Fig. 3) and median nerve block resulted in a similar increase in $T_s$ of the ulnar half of the fourth digit (Fig. 4).

The mechanisms behind the substantial increase in $T_s$ after specific blocking of the median and ulnar nerves are not known in detail. It seems that the first response is an increase in $T_s$ in the fingertips (Fig. 4). This may be explained by the opening of arteriovenous anastomoses in the fingertips caused by the blocking of specific sympathetic nerve fibres. Apparently, these fibres are only present in the median and ulnar nerves. Subsequently, the increased blood flow in the fingertips dilates nearby veins and $T_s$ increases proximally and laterally along these veins, initially causing a very inhomogeneous $T_s$ distribution (Figs 3–5). We therefore speculate that the changes in $T_s$ 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. 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 $T_s$ 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 $T_s$. Therefore, some patients already had elevated $T_s$ at baseline, which would make the detection of an increase in $T_s$ more difficult. Consequently, we may have overlooked an increase in $T_s$ 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 $T_s$ 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 $T_s$ was rapid in onset after both the median and ulnar nerve blocks, we do not think that the lack of an increase in $T_s$ 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 $T_s$ 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 $T_s$ 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 $T_s$ in the dorsal hand area innervated by the radial nerve. However, the specific blocking of the musculocutaneous or the radial nerve does not increase $T_s$ in any area. These results contrast the hypothesis that the blocking of a specific nerve always leads to increases in $T_s$ in the areas innervated by the blocked nerve.

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**Conflict of interest**

None declared.

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