Transcutaneous electrical nerve stimulation (TENS) increases survival of ischaemic musculocutaneous flaps

J. KJARTANSSON,* T. LUNDEBERG,† U. E. SAMUELSON*† and C.-J. DALSGAARD*†

*Department of Plastic and Reconstructive Surgery, Karolinska Hospital, †Department of Physiology and ‡Department of Anatomy, Karolinska Institutet, Stockholm, Sweden


The effect of transcutaneous electrical nerve stimulation (TENS) on the survival of a dorsal musculocutaneous flap was studied in the rat. Postoperative TENS treatment significantly increased the flap survival area in groups of rats receiving different modes of TENS. The flap survival area was up to 95% in the TENS-treated groups compared with 33–45% in the control groups. Repeated (3 days) high intensity (20 mA), high-frequency (80 Hz) TENS applied segmentally at the base of the flap was shown to be the most effective treatment in increasing the flap survival. Preoperative TENS did not increase flap survival area compared with untreated controls. It is concluded that postoperative TENS treatment markedly increases the experimental flap survival area and may be of clinical value for treatment of local ischaemia.

Key words: flap survival, ischaemic flaps, transcutaneous electrical nerve stimulation (TENS).

In many clinical conditions, untreated transient or permanent tissue ischaemia may result in necrosis. Using experimental surgical flaps, many attempts have been made to increase flap survival (Jonsson et al. 1975, Wexler et al. 1975, Jurell & Jonsson 1976, Finseth & Adelberg 1979, Kerrigan & Rollin 1982, Kjartansson & Dalsgaard 1987). Clinical studies have shown that electrical stimulation of the dorsal column and different modes of peripheral stimulation, i.e. vibratory stimulation, acupuncture and electrical stimulation may increase the peripheral blood flow (Kaada 1982, Lundeberg 1985, Itaya et al. 1987). It has been suggested that this increase is due to decreased sympathetic activity and/or the release of vasodilatory compounds (Edholm et al. 1957, Shepherd 1963, Blumberg & Wallin 1987). In the present study we have investigated the effect of transcutaneous electrical nerve stimulation (TENS) on survival of the dorsal musculocutaneous flap in the rat.

MATERIAL AND METHODS

The study was carried out on 120 female albino rats (Sprague-Dawley, weight 180–220 g). The rats were anaesthetized with chloral hydrate (0.4 g kg⁻¹), shaved on the back and a flap designed according to a standard pattern, 2 cm wide and 7 cm long, based on a line between the caudal part of the scapulae (McFarlane et al. 1965, Kjartansson et al. 1987). The flap was raised from the deep fascia of the muscles and included the superficial fascia, panniculus carnosus, subcutaneous tissue and skin. After the flap had been raised it was sutured back in position. Before each
TENS treatment the rats were anaesthetized with chloral hydrate. The TENS stimulator (Delta TENS) produced monopolar square-wave pulses, of 0.2 ms duration. During high-frequency TENS the frequency was 80 Hz, and during low-frequency TENS 2 Hz pulse trains, i.e. a 71 Hz pulse train with a total duration of 84 ms delivered at 2 s⁻¹. The rats received TENS treatment as follows (Table I). Ten rats received high-intensity, high-frequency TENS at the base of the flap for five days, ending two days before surgery (Group 1). Ten rats received high-intensity, low-frequency trains at the base of the flap for 1 h before and after surgery (Group 2). Ten rats received high-intensity, low-frequency trains at the base of the flap for 1 h on day 3 after surgery (Group 3). Ten rats received high-intensity (20 mA), high-frequency (80 Hz) TENS at the base of the flap for 1 h immediately after surgery (day 1) and for 1 h the following two days (days 2 + 3) (Group 4). Ten rats received high-intensity, low-frequency trains (2 Hz) at the base of the flap for 1 h immediately after surgery and for 1 h the following two days (Group 5). Twenty rats received low-intensity (5 mA), high-frequency TENS at the base of the tail (extra segmental stimulation) for 1 h immediately after surgery and for 1 h the following day (day 2) and the third day after surgery (day 4) (Group 6). Ten rats received high-intensity, low-frequency trains at the base of the tail for 1 h immediately after surgery and for 1 h the following two days (Group 7). Ten rats received high-intensity, high-frequency TENS at the base of the flap for 1 h immediately after surgery and the following day as well as on the fourth day after surgery (Group 8). Ten rats received low-intensity, high-frequency TENS at the base of the flap for 1 h after surgery, and the following and third day after surgery (Group 9). Two groups of controls, 10 in each group, were used. Ten rats were anaesthetized only once, i.e. during surgery (Group 10), and 10 rats were anaesthetized during surgery and also on the two following days (Group 11). In the controls the procedure used was identical with that used during TENS except that there was no output to the electrodes.

The percentage survival of the flap was estimated after six days.

For statistical analyses of flap survival between the different groups, the Mann–Whitney U-test was used. Three out of the 120 rats died during the experimental procedure. These rats are not included in the results.

RESULTS

In the controls, i.e. rats undergoing surgery and anaesthetized once (Group 10), or anaesthetized 3 times (Group 11), 44.6% and 33.3%, respectively of the flap survived (Table I). Rats anaesthetized 3 times had a significantly (P < 0.025) lower survival than those anaesthetized once. The statistical analysis of the effect of TENS treatment was carried out by comparing the groups receiving TENS with the group of controls anaesthetized once or 3 times (Table I). Transcutaneous electrical nerve stimulation significantly increased flap survival compared with controls in all treated groups except the group of rats (Group 1) receiving only preoperative TENS treatment. The highest percentage flap survival (94.6%) was seen in the group of rats (Group 8) receiving high-intensity, high-frequency segmental stimulation for 3 days, postoperatively. High-intensity TENS treatment postoperatively resulted in the highest degree of survival, 63.4–94.6% (Groups 2–5, 7, 8).
TENS increases survival of ischaemic flaps

Table 1. Experimental design and effect of TENS on survival area as compared with untreated (control) rats. Mode of treatment: high intensity, 20 mA (Hi) or low intensity, 5 mA (Li). Frequency of stimulation: high-frequency, 80 Hz (H) or low-frequency pulse trains, 2 Hz (L). Application of stimulation: segmental, at the base of flap (S) or extra segmental, at the base of tail (E). Day of treatment: Preoperative (Pre), Postoperative (Post)

<table>
<thead>
<tr>
<th>Group number</th>
<th>Mode</th>
<th>Frequency</th>
<th>Application</th>
<th>Day</th>
<th>Survival area (%)</th>
<th>Increase in survival vs. control (%)</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>H</td>
<td>S</td>
<td>Pre 7–2</td>
<td>10</td>
<td>39.6</td>
<td>24.4</td>
<td>11</td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>L</td>
<td>S</td>
<td>Pre 1 h + Post 1 h</td>
<td>8</td>
<td>77</td>
<td>9.0</td>
<td>73</td>
<td>&lt;0.01</td>
<td>(10)</td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>L</td>
<td>S</td>
<td>Post 3</td>
<td>10</td>
<td>63.4</td>
<td>11.0</td>
<td>42</td>
<td>&lt;0.01</td>
<td>(10)</td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>H</td>
<td>S</td>
<td>Post 1+2+3</td>
<td>10</td>
<td>85.7</td>
<td>11.1</td>
<td>157</td>
<td>&lt;0.001</td>
<td>(11)</td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>L</td>
<td>S</td>
<td>Post 1+2+3</td>
<td>10</td>
<td>82.1</td>
<td>9.9</td>
<td>147</td>
<td>&lt;0.001</td>
<td>(11)</td>
</tr>
<tr>
<td>6</td>
<td>L</td>
<td>H</td>
<td>E</td>
<td>Post 1+2+4</td>
<td>20</td>
<td>44.0</td>
<td>15.0</td>
<td>20</td>
<td>&lt;0.05</td>
<td>(11)</td>
</tr>
<tr>
<td>7</td>
<td>L</td>
<td>E</td>
<td>S</td>
<td>Post 1+2+3</td>
<td>10</td>
<td>73.2</td>
<td>28.7</td>
<td>120</td>
<td>&lt;0.01</td>
<td>(11)</td>
</tr>
<tr>
<td>8</td>
<td>H</td>
<td>H</td>
<td>S</td>
<td>Post 1+2+4</td>
<td>10</td>
<td>94.6</td>
<td>3.7</td>
<td>180</td>
<td>&lt;0.001</td>
<td>(11)</td>
</tr>
<tr>
<td>9</td>
<td>L</td>
<td>H</td>
<td>S</td>
<td>Post 1+2+4</td>
<td>9</td>
<td>57.8</td>
<td>20.4</td>
<td>71</td>
<td>&lt;0.01</td>
<td>(11)</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>Anaesthetized once</td>
<td>10</td>
<td>44.6</td>
<td>9.0</td>
<td>25</td>
<td>&lt;0.025</td>
<td>(11)</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td>Anaesthetized 3 times</td>
<td>10</td>
<td>33.3</td>
<td>14.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TENS treatment applied at a low intensity (Groups 6, 9) did show an increased flap survival (44.0% and 57.8%, respectively). The results show that there is no significant difference if TENS is applied at the base of the flap or base of the tail if the stimulation intensity is high (Group 5 vs. Group 7). However, when using low-intensity stimulation, treatment of the base of the flap (segmentally related) is significantly (P < 0.05) better than treatment of the base of the tail (extra segmentally) (Group 6 vs. Group 9). Furthermore, there is a significant (P < 0.001) difference in survival when comparing high-intensity treatment with low-intensity treatment (Group 8 vs. Group 9). However, there is no significant difference when comparing high-frequency with low-frequency train treatment (Group 4 vs. Group 5). Postoperative treatment is significantly (P < 0.001) better than preoperative treatment (Group 8 vs. Group 1). The results also show that repeated TENS treatments are significantly better (P < 0.05) than one single treatment (Group 5 vs. Group 3), although the choice of days of treatment does not appear to influence the outcome (Group 8 vs. Group 4).

DISCUSSION

The present results show that TENS treatment increases survival of ischaemic tissue in a musculocutaneous flap model in the rat. The highest flap survival was obtained with repeated, postoperative, segmentally applied TENS with high intensity. The flap survival was not related to the frequency used.

Stimulation applied at the base of the flap (segmentally) at a low intensity was significantly better than stimulation applied at the base of the tail (extra segmentally). This difference was not seen when high-intensity stimulation was used.

High-intensity electrical stimulation was significantly better than low-intensity electrical stimulation. This indicates that stimulation of thin afferent nerves is needed to obtain maximal effect.

The mechanism by which TENS increases survival in the dorsal musculocutaneous flap in the rat is not known, although at least two possible ways may be suggested: (1) that TENS activates larger diameter sensory nerve fibres which may inhibit activity in sympathetic vasoconstrictory neurons (Rowell 1981); and/or (2) TENS activates small to medium-size sensory neurons to release vasodilatory neurotransmitters (Foerster 1933, Lembeck & Gamse 1982, Couture & Cuello 1984, Bell et al. 1985, Kaada 1987). It was shown earlier that antidromic stimulation of sensory nerve fibres causes cutaneous vasodilation (Hinsey & Gasser, 1930). A release of the neuropeptide substance P (Lembeck & Holzer 1979) and calcitonin gene-

ACT 134

ACT 134
related peptide CGRP may be responsible for this effect (Brain et al. 1985; Brain & Williams 1985, Gamse & Saria 1985). In this context it is interesting to note that pretreatment with capsaicin, a pungent extract from Hungarian pepper which is known to deplete sensory neuropeptides, decreases the survival of the dorsal musculocutaneous flap (Kjartansson et al. 1987). Pretreatment of rats with anti-adrenergic drugs has been shown to increase survival of the musculocutaneous flap in the rat (Jonsson et al. 1975, Jurell & Jonsson 1976), although the survival was less than that reported in the present study with TENS. In contrast, it has recently been shown that postoperative treatment with CGRP at low molar doses dramatically increases the flap survival (Kjartansson & Dalsgaard 1987) to a rate comparable with the survival obtained with TENS treatment. The finding that high-intensity segmental stimulation is not significantly different from extra segmental stimulation suggests that an active compound is released into the circulation rather than a direct action on segmental sympathetic neurons. However, a complex reflex arrangement or transmission of high-frequency TENS current over segments cannot be excluded (Rowell 1981). In the case of low-intensity stimulation a local release may explain the positive effects on flap survival. However, further studies will be needed to elucidate the mechanisms by which TENS acts.

In conclusion, TENS treatment dramatically increases the survival of experimental musculocutaneous flaps in rats. The mechanism for this action is not known, but it may be suggested that TENS activates sensory nerve fibres that interact with sympathetic vasoconstriction neurons and/or that TENS activates sensory nerve fibres to release vasodilatory compounds. We also suggest that TENS may have clinical value in treating local ischaemia.

The assistance of Ms U. Lindgren in preparing the manuscript is greatly acknowledged.

This study was supported by grants from the Swedish Society of Medicine, Torsten and Ragnar Söderbergs Stiftelse, Swedish Medical Research Council (7216), Åke Wibergs Stiftelse and SRA. The present study was approved by the ethical committee of Karolinska Institutet.

REFERENCES


TENS increases survival of ischaemic flaps


