Impact of surgical intervention and postoperative pain on electrical skin resistance at acupuncture points: an exploratory study

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ABSTRACT

Objectives One theory about acupuncture suggests that pathological processes can cause measurable changes in electrical skin resistance (ESR) at acupuncture points (APs). Although the theory has yet to be proven, ESR measurements (ESRMs) form a frequently used part of contemporary acupuncture. The aim of this study was to test the so-called ‘electrical responsiveness’ of APs in the setting of a defined operative trauma.

Methods ESRMs (n = 424) were performed at the APs and surrounding skin of GB34 and ST38 in 163 participants using an impedance meter array developed for the purpose of ESRMs. For each group the percentage of measurements with a significantly different ESR between the APs and the surrounding skin was calculated and compared with each other. Measurements of four groups were compared: healthy control subjects (n = 30) and patients after ophthalmic (n = 29), hip (n = 42) and shoulder (n = 30) surgery. The influence of postoperative pain intensity was also assessed.

Results Group comparison showed no significant differences for ST38. The ESRMs at GB34 had a significantly higher percentage of measurements with an increased ESR after ophthalmic (23.2%) and hip (22.2%) surgery, but not after shoulder surgery (7.5%). Subgroup analysis showed that an increase in pain intensity tended to lead to a decrease in the number of APs with ESR changes.

Conclusion These results suggest that reactive changes in ESR at APs might exist. Pain and alertness seem to have an impact on ESR at APs. However, the current data do not allow for conclusions to be drawn concerning the clinical use of ESRMs.

INTRODUCTION

Acupuncture treatment is gaining in importance with a variety of studies confirming its efficacy in the treatment of various disorders.1–2 However, while evidence for the clinical efficacy of acupuncture is growing, questions are being raised concerning the specificity of acupuncture points (APs).3–4 In order to increase the general acceptance of acupuncture, a better understanding of how APs and meridians function is needed.

One theory about the specific nature of APs suggests that electrical skin resistance (ESR) is different from the surrounding area,5,6 and that a change in the ESR at an AP can be the reflection of a pathophysiological condition of the patient.5,9 Based on this assumption of an ‘electrical responsiveness’ of APs, commercially available devices for electrodermal testing have been developed for acupuncture point location as well as for use as diagnostic and therapeutic tools.10,11 Electrical skin resistance measurements (ESRMs) have been established as an integral part of contemporary acupuncture.5 However, the scientific support for an electrodermal distinctiveness of APs is controversial,12 and there is even less evidence for the electrical responsiveness of APs.5,13–15

ESRMs have proved difficult to verify due to their rapid variability and variations in measurement techniques.16 In this investigation we used a method that minimises the influence of typical disturbances.17 It consists of a square of 64 electrodes that are measured in rapid succession. In a previous investigation we showed that the results of this method were reproducible and that some, but not all, APs possess the claimed electrical properties.18

We hypothesised that surgical intervention forms a considerable stimulus that would be reflected by changes in ESR at the corresponding AP. We also considered whether the type of surgical intervention might affect the type of change (eg, one type of surgery resulting in a decreased ESR while another leads to an increased ESR). Lastly, we investigated the correlation of these findings with the subjects’ reports of pain. We selected the AP ST38 as an example of a highly specific experience-based point (ST38) and GB34 as an example of a standard Traditional Chinese Medicine
(TCM)-based point that would be part of a postoperative pain treatment scheme in all three study groups.

**MATERIALS AND METHODS**

**Participants**

One hundred and sixty-three healthy volunteers and patients took part in the study after signing an informed consent form. Table 1 shows the composition of the different groups (age, gender, pain intensity, time interval from anaesthesia to measurements and type of anaesthesia).

**Inclusion and exclusion criteria**

The inclusion criteria for the four groups were as follows: shoulder surgery group (SG): injury of rotator cuff, impingement syndrome, upper humerus fractures, lateral clavicle fracture, shoulder prosthesis; hip surgery group (HG): total hip arthroplasty, dynamic hip screw, revision of total hip arthroplasty, chondromatosis/exostosis or refixation of trochanteric muscles; ophthalmic surgery group (OG): keratoplasty, glaucoma-surgery, vitrectomy, strabismus surgery, scleral buckling; control group: general good health.

Exclusion criteria were critical heart, lung, liver and/or kidney diseases with possible influence on ESR; pregnancy; neurological diseases of any kind; and skin irritations/lesions or acupuncture treatment on the measured APs in the 4 weeks before participation in the study.

**Setting and procedures**

The study was carried out at the Department of Anaesthesiology, the Department of Ophthalmology and the Department of Surgery at the University of Munich, Germany. Healthy volunteers were recruited on the campus of the Ludwig-Maximilian-University, Munich, Germany.

ESRMs were performed in three study groups (patients after shoulder, hip and ophthalmic surgery) and one healthy subject control group. The control group was divided into two subgroups for ST38 and GB34 to achieve an age distribution corresponding to the hip group for GB34 and to the shoulder group for ST38.

In the surgery groups, ESRMs were taken in the recovery room as soon after surgery as possible. Owing to the organisational properties of the different operations, the time interval between surgical intervention and ESRMs differed between the groups. In the control group, subjects were advised to rest for 15 min before measurements were taken.

Postoperative pain intensity was measured on an 11-point visual analogue scale (VAS) where 0=no pain and 10=worst possible pain.

**Acupuncture points**

The following APs were selected for ESRMs; their localisation was determined as described in the current standards of TCM:

- **ST38 ‘Tiaokou’**, located 1 Cun (= the width of the patient’s thumb) laterally from the anterior crest of the tibia and 8 Cun distally from the patella.
- **GB34 ‘Yanglingquan’**, located in the depression anterior and inferior to the head of the fibula.

ST38 has been shown to be a point specifically for the treatment of shoulder problems whereas GB34 is a common pain point for the treatment of disorders of the musculoskeletal system and disorders related to the TCM organs of liver/gallbladder (eg, the eye).

**Device**

The ESRM device consists of an array of 64 electrodes on a flexible plastic foil surface (6x6 cm; 8 mm between the centres of each electrode) that are measured repeatedly in rapid succession (average scanning time 15 ms) with direct current (max flow of 20 μA; mean voltage 4.8 V). ESR values are indicated in arbitrary units.

The array has been has been approved as safe by the German Technical Inspection Authority and tested for the validity and reliability of its results; each single electrode has been tested against known resistances and, in human probands, more than 580 correlation coefficients (Spearman) were calculated between a series of five consecutive ESRMs with only 5.6% lower than 0.85, indicating highly reproducible measurement results.

**Procedure**

The measurement process is shown in figure 1. The electrode array was placed on the skin area in which the AP is known to be found. No palpation or manipulation was allowed before ESRMs. The edges of the array were
marked on the skin with a standard permanent marker. After the recording procedures were completed, the APs were localised by an independent investigator who was experienced in acupuncture and blinded to the results of the ESRMs. A template was used to match the array electrodes and the determined AP location.

Statistical analysis
The study was planned as an exploratory investigation. Microsoft Excel 2003 and SPSS (16.0 Windows) were used for the statistical analysis. Differences in the ESR were evaluated by the Wilcoxon rank sum test. The area of 3×3 electrodes defined as AP was compared with the rest of the electrodes on the array. The measured values of electrodes corresponding to other nearby APs were excluded from the evaluation. Mostly this was the case for the electrodes corresponding to ST36 on the measurements of GB34. P values <0.05 were considered statistically significant. Thus, for each measurement a p value was obtained, indicating whether in this single measurement the AP showed a significantly different electrical resistance than the surrounding skin. The percentage of ESRMs with a significantly different ESR at the AP was calculated for each group.

False discovery rate was used as an adjustment for multiple testing. Instead of adjusting the p value as the Bonferroni procedure, false discovery rate calculates the so-called critical significance level d for each p value.

The percentage of ESRMs with a significantly different ESR at the AP from that of the surrounding skin was calculated and compared between the different groups by the χ² test. Differences in pain intensity and in the time interval between surgical intervention and ESRMs were assessed using the Student t test.

RESULTS
A total of 444 ESRMs were taken from 163 subjects (table 1). One hundred and twenty ESRMs were performed on 30 subjects (ST38 and GB34 bilaterally) in the SG, 84 ESRMs on 42 subjects (Gb34 bilaterally) in the HG, 116 ESRMs on 29 subjects (ST38 and GB34 bilaterally) in the OG and 124 ESRMs on the subjects in the control groups (either ST38 or GB34 bilaterally). Twenty ESRMs had to be excluded from further evaluation for the following reasons: (1) the AP was located on the edge of the measuring field’s array with an insufficient number of electrodes left for a valid evaluation (localisation problems due to the blinded measurement process) (11 ESRMs); (2) ink mark fade (1 ESRM); (3) the patient’s calves were too big for proper fixation of the array (2 ESRMs excluded); (4) skin irritations/lesions were found in the measured skin area (3 ESRMs); (5) 1 ESRM of GB34 distal to a total knee replacement was excluded; (6) sensory dysfunction on one leg led to exclusion of the two measurements on the dysfunctional side.

Four hundred and twenty-four ESRMs were left for further evaluation of group differences in ESR. The results are shown in figure 2 and table 2.

With regard to ST38, no statistically significant differences were found between the different groups. Significant differences between the groups were only observed for ESRMs of GB34: patients in the OG (25%) and HG (22%) had a significantly higher percentage of increased ESR at GB34 than the control group (8%); however, this was not the case for patients in the SG (8%). These differences were also statistically significant between the OG and SG and between the HG and SG.
Pain intensity was assessed on an 11-point VAS. Patients in the SG registered significantly more pain than patients in the other study groups (table 1). Pain intensity was 2.8±2.7 in the SG, 0.2±0.8 in the HG and 0.03±0.2 in the OG. To assess the impact of pain intensity on ESR in the SG (figure 3), ESRMs were divided into two subgroups (pain intensity ≤4 and >4). In the group with limited pain (≤4) there were more ESRMs with a significantly different resistance at the AP than in the group with medium and severe pain (>4). None of these differences reached statistical significance, probably due to the low sample size.

In the SG, the time interval between surgical intervention and measurements was significantly increased compared with the other groups (1.4±1.3 h vs 0.5±1.0 h and 0.5±0.2 h) (table 1). We assume that alertness increases with time after anaesthesia/sedation. Subgroup analysis of the impact of time after surgical intervention in the SG showed a higher number of APs with a significantly lower ESR as the interval after surgery was increased. Because of the low sample size and unequal distribution of measurements in this group, no statement about statistical significance could be made.

We performed an analysis to determine whether the kind of anaesthesia administered to the patients had an influence on ESR at GB34. The percentages of APs with an increased/decreased resistance were not different between the OG (general anaesthesia) and the HG (spinal anaesthesia). In the SG all 50 patients received general anaesthesia; 14 also had a regional pain catheter. In the subgroup with a pain catheter, the number of ESRMs with an increased resistance at the AP was non-significantly reduced compared with the subgroup with no pain catheter (p=0.058). Mean pain intensity was 1.4±2.3 VAS in the subgroup with the regional catheter for pain control and 3.9±2.5 VAS in the subgroup without the catheter.

**DISCUSSION**
This study was performed to investigate the theory that electrical properties of APs change according to variations

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**Table 2** Numbers of electrical skin resistance measurements (ESRMs) at two acupuncture points in different groups and numbers of measurements with significantly higher and lower resistance over the acupuncture point compared with the surrounding skin

<table>
<thead>
<tr>
<th></th>
<th>Control group</th>
<th>Hip group</th>
<th>Shoulder group</th>
<th>Ophthalmic group</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB34-ESRMs total</td>
<td>60 (100%)</td>
<td>81 (100%)</td>
<td>53 (100%)</td>
<td>56 (100%)</td>
</tr>
<tr>
<td>GB34-ESRMs with lower ESR (p&lt;0.05)</td>
<td>15 (25.0%)</td>
<td>14 (17.3%)</td>
<td>13 (24.5%)</td>
<td>10 (17.9%)</td>
</tr>
<tr>
<td>GB34-ESRMs with higher ESR (p&lt;0.05)</td>
<td>5 (8.3%)</td>
<td>18 (22.2%)</td>
<td>4 (7.5%)</td>
<td>13 (23.2%)</td>
</tr>
<tr>
<td>ST 38-ESRMs total</td>
<td>63 (100%)</td>
<td>–</td>
<td>54 (100%)</td>
<td>57 (100%)</td>
</tr>
<tr>
<td>ST38-ESRMs with lower ESR (p&lt;0.05)</td>
<td>13 (20.6%)</td>
<td>–</td>
<td>10 (18.5%)</td>
<td>10 (17.5%)</td>
</tr>
<tr>
<td>ST38-ESRMs with higher ESR (p&lt;0.05)</td>
<td>12 (19.1%)</td>
<td>–</td>
<td>9 (16.7%)</td>
<td>12 (21.1%)</td>
</tr>
</tbody>
</table>
in the subjects’ physical status. We hypothesised that surgical intervention would reveal a difference in these electrical properties and, furthermore, that surgery at different locations may have a differential effect on skin resistance at selected APs. We compared three different surgery groups to the results in the two control groups. It can be argued that a more desirable setting would be a preoperative and postoperative measurement but, unfortunately, this is not possible in the context of this investigation since surgery usually follows an acute or chronic disorder that itself could be expected to result in ESR changes.

When performing ESRMs, technical confounders always have to be discussed as these measurements are prone to interferences. We used an ESRM device that has been designed to minimise confounding factors by creating equal conditions for all compared electrodes regarding skin temperature, fixation pressure and angle and duration of measurement. The reliability of this array has been shown in a previous investigation. Furthermore, it could be argued that the position of the AP on the array could influence the measured values as, for example, a central position might result in higher skin humidity by sweat production. Owing to the blinded localisation process of the AP, the position of the AP on the array varied and 11 measurements even had to be excluded because the AP was located outside the measured area or too near to the edge. We are therefore certain that our findings were not influenced by technical confounding factors.

A further limitation might be the fact that in some measurements we had to exclude from evaluation electrodes corresponding to nearby electrodes (e.g., ST36 in measurements of GB34). This was the case for six ESRMs. A maximum of nine electrodes per measurement were excluded, leaving 43 for comparison.

One explanation for missing ESR differences at GB34 in the SG may be the heterogeneous composition of the study groups (table 1). The pain intensity and the time interval between surgical intervention and ESRMs were significantly higher in the SG than in the other groups. An increased time interval between surgical intervention and ESRMs can be assumed to result in an increase in alertness and sympathetic activity. The absence of ESR changes in the SG could be due to the higher level of sympathetic nervous system activation in this group. This theory is suggested from subgroup analysis of the SG: patients with no or mild pain showed more APs with significant differences between AP and surrounding skin than patients with medium or severe pain. This observation indicates that ESR changes due to pain might interfere with ESR changes at APs due to surgical effects. However, as this observation did not reach statistical significance, further investigations are warranted.

Missing changes at ST38 could be due to the various specific anatomical characteristics that are currently discussed for APs. APs are said to be associated with special anatomical characteristics—for example, the location above perforation sites of blood vessels through fascias have been discussed as well as a higher local density of vessels, nerves or sweat glands, connections to vessel nerve sheaths and connection to preferential spots of muscular trigger points.

There is still little scientific evidence for these theories, with most of the reports being only anecdotal. Nevertheless, it has been shown that the blood flow under an AP can be higher than under reference points. An association between APs, trigger points and fascial structures has been shown. Given the finding that ESR is altered on the skin over a trigger point, it is possible that there might be a connection between specific anatomical characteristics and observed changes in ESR.

Little is known about the electric properties of the human skin in general, but there are some observations on influencing factors. ESR changes are not restricted to APs but the whole skin side of the human body can be described as electrically inconsistent, with the pattern of its distribution being mosaic-like. Despite many investigations, the physiological origin and function of electrical resistance of the skin is still unknown. One theory states that ESR represents a residue of an early coordination system during embryogenesis, but there is little scientific evidence to support this theory. Other findings suggest that ESR can be influenced by sympathetic nervous system activation. In addition, an association of ESR with pain intensity has been shown. The observation of ESR changes and variability have been validated for the monitoring of nociceptive stimulation and pain.

Knowing that human ESR in general can be altered by different factors such as sympathetic activity and pain,
and looking at the anatomical specialities to which APs are said to be linked, it seems likely that local ESR changes at APs are a combination of special anatomical conditions and certain influences. There are different ways in which anatomical conditions at APs could result in locally measurable differences in ESR, and these are shown in the hypothetical diagram in figure 4.

We consider that our findings support the theory that APs possess a certain electrical responsiveness as a reaction to influences on the body. Our findings also provide helpful information in the ongoing discussion about the nature and specificity of APs. However, in the >60% of our measurements we did not find significant changes so, at the current stage of this research, it is not possible to draw the reverse conclusion that ESR changes are reflections of pathological processes in the corresponding organ, as in the framework of TCM. Further investigation is needed to help to evaluate the physiological basis, the impact of local anatomical changes and pain and sympathetic nervous system activity on ESR at APs. Future research should employ a pre–post design to explore intra-individual changes at APs in reaction to a defined stimulus in order to gain a better understanding of the impact of these on our findings.

CONCLUSIONS
At the current stage of research it is not possible to assess the effectiveness of using measured ESR differences for diagnostic or therapeutic purposes. However, our results suggest that APs can be characterised by differences in the ESR compared with the surrounding areas. In addition, the results suggest that APs possess an electrical responsiveness to external stimuli, but this needs confirmation by further trials.

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Contributors SK: conception, design, acquisition, analysis and interpretation of data, drafting of the manuscript and final approval; DZ: acquisition of data, analysis and interpretation of data and final approval of the manuscript; DK: analysis of data, critical revision of manuscript and final approval; BW: development of array, critical revision of manuscript and final approval; FK: technical support with development of the array, analysis of data, critical revision of manuscript and final approval; KZ: acquisition of data, drafting of the manuscript and final approval; LL: acquisition of data and final approval of the manuscript; JF: acquisition of data, drafting of the manuscript and final approval; UE: statistical analysis and interpretation of data, drafting of the manuscript and final approval; PL: drafting of the manuscript and final approval; DI: conception, design and interpretation of data, drafting of the manuscript and final approval.

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