12th IMEKO TC4 International Symposium
Electrical Measurements and Instrumentation
September 25–27, 2002, Zagreb, Croatia

ELECTRONIC SKIN – TEST DEVICE FOR ELECTROSURGICAL NEUTRAL ELECTRODES

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Abstract – Quality test for neutral electrodes (grounding plates used in electrosurgical operations) with volunteers and thermo cameras are difficult to perform and expensive. A new test device "electronic skin" simulates the relevant electrical features of human skin. The starting point of development was a model calculation of the human thigh and the resultant current densities and power losses causing the temperature increase. From these findings the electronic skin was developed. This device consists of a three dimensional resistor network representing the various skin layers and muscle tissue, and a temperature sensing array (one transistor for each cm²) to measure the resultant temperature increase after a standardized current load (700 mA hf current during 60 s). To prove the compatibility of the new device with the tests required according to the AAMI HF 18 standard, the comparison of test results with thermo camera images on volunteers showed a sufficient coincidence, which proves the applicability of this test device to replace volunteer experiments.

Keywords: electrosurgery, neutral electrode, volunteer experiments.

1. INTRODUCTION

Electrosurgery means cutting and coagulating tissue by means of an hf current. The current flows into the tissue via the active electrode ("electrical knife") in the surgeon's hand and must flow back to the hf generator via the neutral electrode. The principle current flow of an electrosurgical procedure is sketched in Fig. 1

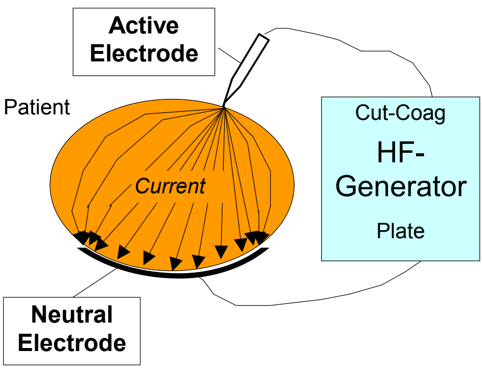

Fig. 1. Principle of an electrosurgical operation

Neutral electrodes (dispersive electrodes, grounding plates) are safety relevant accessories in electrosurgery. In contradiction to the active electrode a neutral electrode must not heat the patient's skin in excess of 6°C during the hf-current pass and the electrode's design and quality must be tested according to AAMI HF 18 standard [1].

One test methods is a **volunteer experiment** under standardized conditions (AAMI HF18, 700 mA hf current during 60 s) with a thermo camera to measure the temperature increase on the skin under the neutral electrode. This method is laborious (10 volunteers for one significant test!), time consuming and expensive (thermo camera, clinical environment) and cannot be used routinely for quality tests.

The result of a typical volunteer experiment is shown in Fig. 2. The temperature increase in this experiment was appr. 3,5°C at the hottest spot..

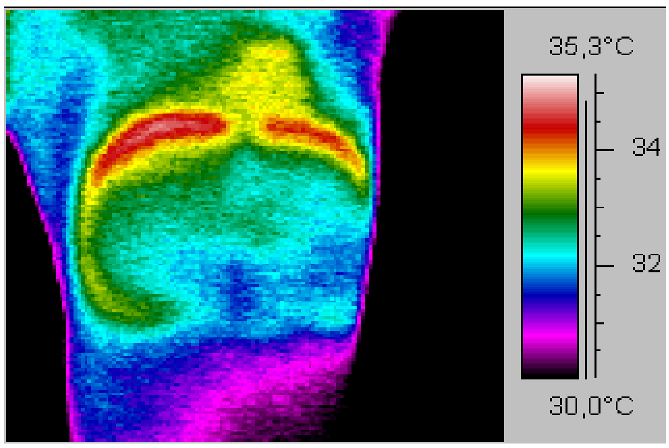

Fig. 2. Thermo camera image of a volunteer experiment

It is easily understandable, that this laborious procedure cannot be used for routine tests or for quality assurance tests, thus an alternative solution must be found

An alternative is a **suitable structured surrogate medium** (AAMI) which simulates the electrical features of the patient's skin found in electrosurgery. The solution is an electronic simulation of the skin → **electronic skin.**

Since the current distribution and current density inside the thigh cannot be measured, a model calculation must clarify these details before an electronic model can be designed.

2. MODEL CALCULATION

Human skin at the preferred locations for application of a neutral electrode (e.g. thigh, upper arm, buttock) consists of several layers with various electrical conductivities.

From the only rarely available information about electrical properties of skin in the literature [2, 3] the thigh-model is composed of the various skin layers, the muscle and the bone. In detail the model contains the **epidermis** (0,1 mm thickness, 2000 Ohm cm specific conductivity), **corium** (1,5 mm, 290 Ohm cm), **hypodermis with fat** (15 mm, 1600 Ohm cm), **muscle** (65 mm, 200 Ohm cm) and **bone** (no conductivity) as shown in Fig. 3. The neutral electrode for the model is a standard adult type with appr. 130cm² active area (80 x 170 mm).

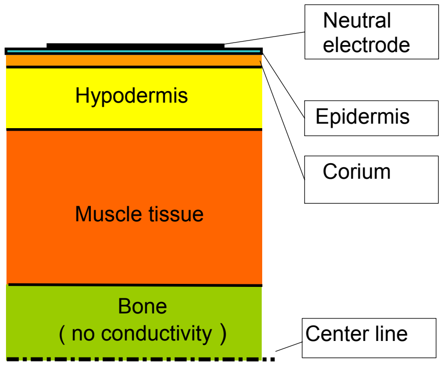

Fig. 3. Skin layers of a thigh used in model calculations and as basis for the resistor network.

The **calculation** of this problem requires a three-dimensional modeling of a thigh and a neutral electrode with rounded edges [4, 5]. We chose a finite element solution with a program designed by Doz. Biro, Technical University Graz.

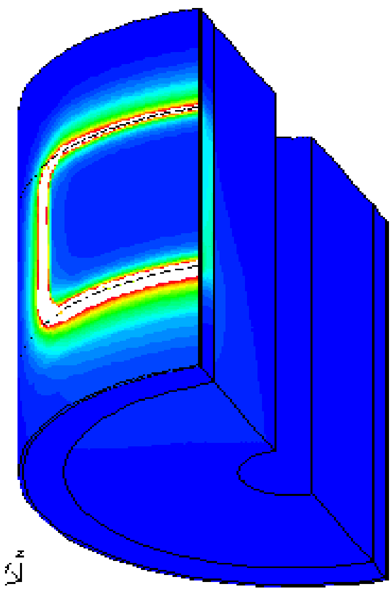

Fig. 4. Current densities (proportional to energy density and corresponding temperature increase) in a cylinder model

The current source is the bottom of the cylinder model, the current passes through the thigh volume to the neutral electrode. The volume conductor causes a current concentration around the edges of the neutral electrode (the socalled "**edge effect**") and therefor an excessive heating at the highest current densities. This edge effect is also indicated in the sketch Fig. 1. A calculated current density distribution in a realistic model of a human thigh shows Fig. 4.

The correspondence with the volunteer experiments as shown in Fig 2 was a good prove for the correctness of the model [6]. The **electronic simulation** of the skin must therefor reproduce the current flow inside the skin and muscle tissue to generate the same energy distribution (and heating effects) as in the patient's skin.

3. ELECTRONIC REALIZATION

The device is realized as a stack of pcb-boards with a **gold plated surface** for the attachment of the neutral electrode under test. This surface is electrically devided into **1 cm² sized squares**, each of them connected to a **network of resistors** at the rear side. This network corresponds to the specific impedance in horizontal and vertical direction of the respective skin layers for a prism with 1 cm² cross section each. Fig. 5 gives an impression of this network where a group of 6 resistors each represents one skin layer.

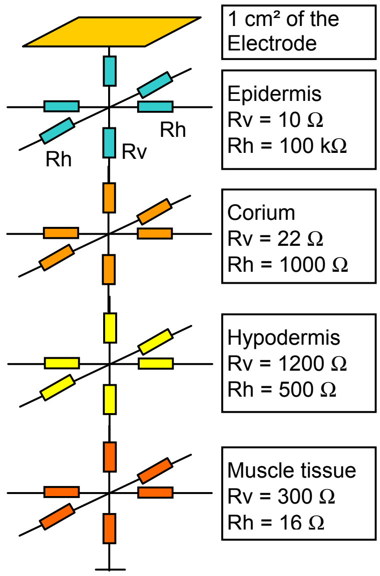

Fig. 5. Three dimensional R-network for representation of the electrical features of the human skin.

By eliminating negligible components and combining resistors in series the network can be reduced significantly. Each step of reduction was accompanied with the calculation of the power distribution and a comparison with the model results

For a cross section through the neutral electrode and the center line of the model cylinder, corresponding to the central cut through the model as shown in Fig 4, the power in the resistors under standard AAMI-load was calculated and displayed in figure 6

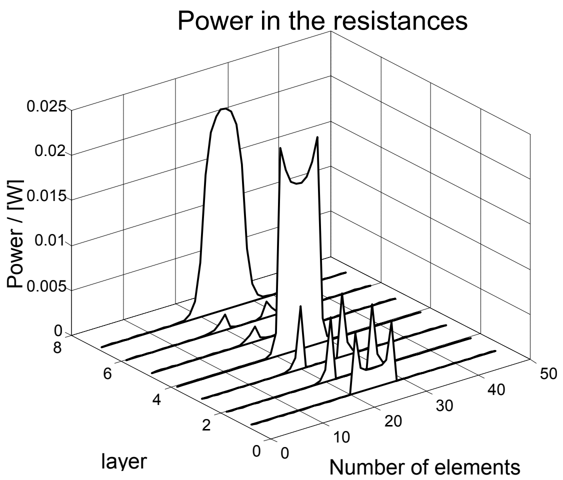

Figure 6: Partial power in the resistor layers

Layer 1 represents the epidermis, layers 2 to 4 the corium and layer 5 to 7 the hypodermis. Here again it can be seen, that the corium is the critical zone for the temperature increase. The power inside the hypodermis (layer 7), however, is spread over a comparatively larger volume, therefor causing a minor temperatur increase.

For the estimation of temperature increase the human skin can be assumed as „primarily water" and with the thermal equivalent (4,2 Ws/K cm³) it is possible to estimate the temperature increase independently for the skin layers. Fig. 7 shows the details

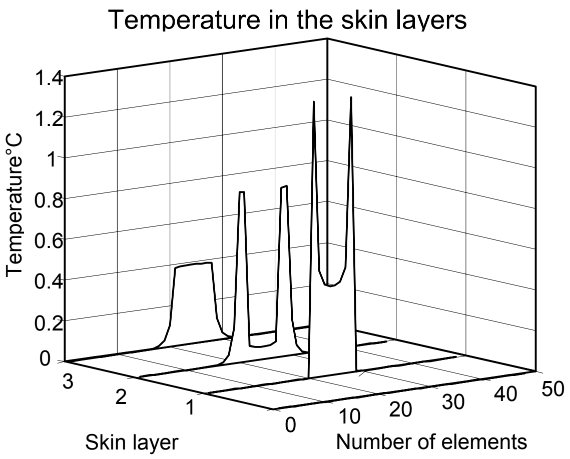

Fig. 7: Estimated temperatures in the skin layers

Layer 1 represents the epidermis, layer 2 the corium and layer 3 the hypodermis. Although the partial temperature in the epidermis (0,1 mm thick) is higher, their influence is reduced by the much larger volume of the corium (1,5 mm thick). This result proves that the chosen resistor network (in the reduced version) represents a suitable tool to simulate the human skin. The temperature increase of layer 1 (epidermis) is restricted to the width of the electrode (element 20 to 28) whereas the corium has a broader temperature profile. From layer 2 (corium) the width of the edge effect (appr. Element 16 to 32) exceeding the width of the neutral electrode can be deduced. This result is in accordance with the thermo camera pictures and the model calculation and therefor a prove for the chosen network. In this device resistors instead of tissue were heated by the current passing through it.

The power loss P [W] in the resistor during a certain time t [s] causes a temperature increase according to the energy loss E = P.t [Ws = J]. The temperature increase is independent of the value of the resistor [Ohm], however, the temperature increase is not the same as for a water volume under the same energy input. Our experiments showed that the temperature of the resistor has to be multiplied with a factor of 1,7 to correspond with the water temperature.

For the **temperature measurement** a bipolar transistor is used with it's temperature depending base emitter voltage. The absolute value (appr. 600 mV), however, is varying significantly from one transistor device to the next (depending on internal structure) but the voltage drop per centigrade temperature increase is a constant (-2 mV/°C). Since only the temperature difference before and after the heating procedure is to be measured, the voltage difference gives the temperature dependent change and cancels out the absolute value of the base emitter voltage.

For each square centimeter of resistor network one **transistor** is in thermal contact to measure the local temperature of all resistors representing the 1 cm² prism of the skin. The temperature dependend base-emitter voltage is scanned by a computer controlled multiplexer network. By comparing the temperature before and after the application of the standard load (700 mA during 60 s for adult sized neutral electrodes, AAMI) the relevant "temperature increase" is calculated as the difference of the local temperature values.

4. RESULTS

In a first version of the device the **direction dependence** towards the operation site was **neglected** [6, 7]. Nevertheless the results show a close correlation with the calculated model and some similarities with the volunteer experiments. The most important result of these tests is the demonstration of the role of the hypodermis and fat thickness of a test person, which could be shown by varying the respective impedance values of the resistor network. Fig. 9 shows the result for a "thermal sensitive volunteer" with a hypodermis thickness of 30 mm, for comparison Fig. 10 and 11 show the same neutral electrode with skin thicknesses of 20mm and 10 mm.

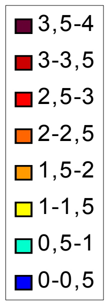

Fig 8 Temperature scale for GPTest3 measurements

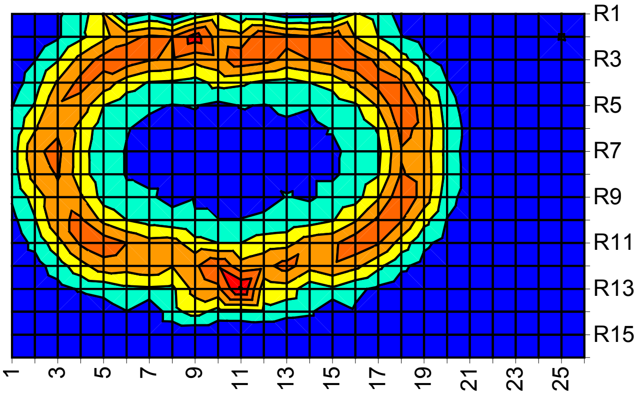

Fig. 9. GPTest result with 30 mm hypodermis.

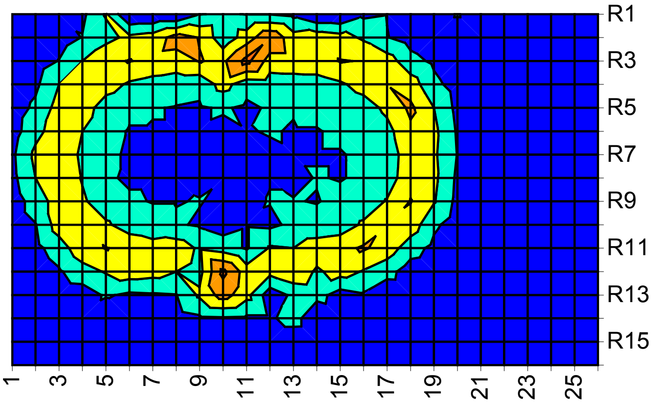

Fig. 10. GPTest 3 result with 20 mm hypodermis.

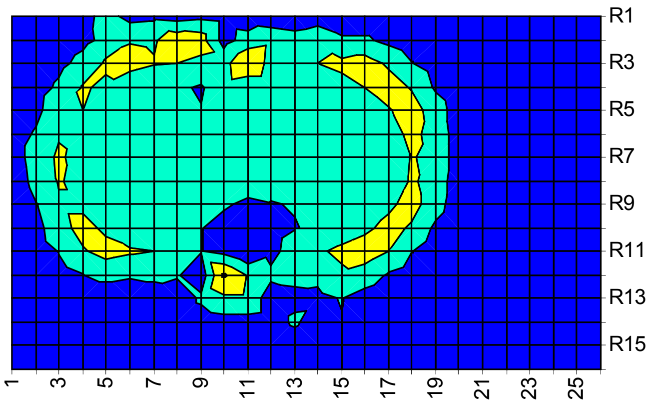

Fig. 11. GPTest 3 result with 10 mm hypodermis.

These result show a lower temperature for lower fat content at the edges of the neutral electrode but an increase of temperature inside the electrode area.

The improved version of the GPTest 3 device includes a **direction dependence** resulting in a higher temperature at the leading edge of the electrode. Test measurements with several types of neutral electrodes under various test conditions showed a close correlation with the thermo camera images measured in volunteer experiments. The "electronic skin" therefor can serve as replacement for the volunteer experiments with the advantage to yield **reproducable results at low cost within a short time**. A typical measurement result with the same electrode type as in fig 2 is shown in Fig. 12

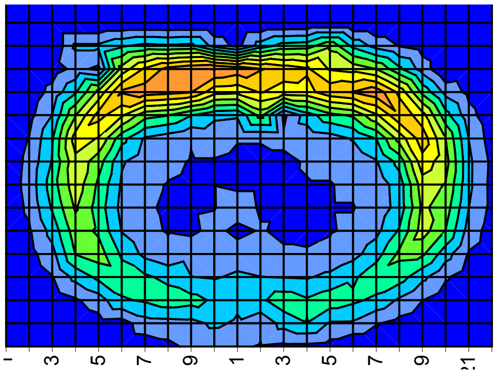

Fig. 12. Test result with the new device shows the same temperature distribution as found in volunteer experiments.

4. CONCLUSION

This new device can be used for quality test in a production process and for evaluation of new designs of neutral electrodes.

5. REFERENCES

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