Skin resistance during square-wave electrical pulses of 1 to 10 mA

Article *in* Medical & Biological Engineering & Computing · December 1977

DOI: 10.1007/BF02457927 · Source: PubMed

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Med. & Biol. Eng. & Comput., 1977, 15, 679–687

Skin resistance during square-wave electrical pulses of 1 to 10 mA

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Abstract—*Several problems concerning an electrical model equivalent to the skin are discussed. The two components of pure resistance, derivable from the model, were tested with square-wave electrical pulses of 1 to 10 mA. The larger resistance component, shown to be localised in the stratum corneum, varied markedly with the current intensity, the intensity of a previous pulse and the interval between the pulses. This component decreased with time and the decrease was dependent on the amount of electrical charge transferred through the skin. When constant-voltage pulses were used, the decrease could be equated to a process that reinforces itself. The smaller resistance component showed only relatively small variations with the different stimulus properties previously mentioned. It was concluded that the current intensity of transcutaneous electrical stimulation can only be controlled satisfactorily when current-regulated stimuli are used.*

Keywords—*Skin resistance, Transcutaneous electrical stimulation*

1 Introduction

THE transcutaneous electrical stimulation of nerves and muscles is often used in therapy or research studies. These include electromyography and rehabilitation, the suppression of pain, evoked reflexes and communication when other senses are impaired. Transcutaneous stimulation is also used for the study of pain perception or as aversive stimulation in psychological research. Square voltage or current pulses in the range 1 to 10 mA are frequently used for these purposes. Many studies of skin impedance have been carried out with alternating or direct current of intensities lower than 1 mA, but little information is available about the effects of brief direct currents of higher intensity. For this reason a few experiments with square-wave pulses in the range 1 to 10 mA were undertaken.

2 Methods and materials

2.1 *Study of skin resistance with square voltage pulses*

An electrical model equivalent to the intact human skin has originated from the early work of COLE (1933) and BARNETT (1938) on the phase angle of human skin. The model has been confirmed by STEPHENS (1963) who worked with direct currents. It consists of the parallel connection of a fixed capacitance C_p and a resistor R_p, in series with a resistor R_s (Fig. 1). R_p varies nonlinearly with the current intensity, without any time lag. The model is an oversimplification and has been elaborated by LYKKEN (1971). Nevertheless, it is still useful to explain the response of the skin to an electrical stimulus. The model is illustrated by applying a 1 ms wide square voltage pulse (Fig. 2*a*). The resistance R_s may be estimated by dividing the applied voltage by the initial or peak current. During the pulse, the capacitor C_p charges. A fixed capacitance shunted by a nonlinear resistance which permits a leakage current does not charge according to a simple

First received 2nd July, 1976 and in final form 25th January 1977

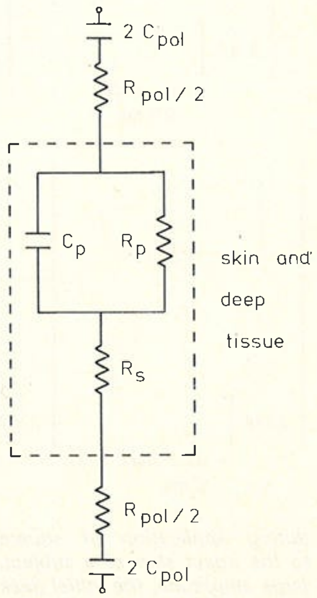

Fig. 1 An equivalent electrical model for skin and deep tissue in series with the polarisation impedance (R_{pol}, C_{pol}) of the electrode-electrolyte interface

exponential law (STEPHENS, 1963). The time properties of charging depend on C_p, R_p, R_s and the applied voltage. This implies that the position and size of the electrodes determine if, for a certain pulse duration and voltage, the current flow falls to a near asymptotic level at the end of the pulse. If this is the case, dividing the applied voltage by the instantaneous current at the end of the pulse gives an approximation of (R_p+R_s), so that R_p can be estimated.

2.2 *Subjects*

Four normal subjects, aged 20 to 28 years, participated in all experiments. The data shown are the means of the individual values. Averaging appeared to be justified because the intersubject variability of the data was small. Only the proportional changes of R_s and R_p are of interest, since the absolute values of these variables depend on the position (ROSENDAL, 1943) and contact area (LYKKEN, 1971) of the electrodes.

2.3 *Apparatus and electrodes*

In our experiments square constant-voltage or constant-current pulses of 1 ms duration were used. The d.c. intensity of the voltage pulses refers to the instantaneous current level at the end of the pulse.

The voltage pulses used were generated by a Grass S88 stimulator fitted with a SIU 5 stimulus isolation unit (output impedance 1000 Ω) and were observed on a Hewlett–Packard 1200B oscilloscope. The current through the subject was observed by recording the voltage drop across a 100Ω series resistor on the oscilloscope. R_s and R_p could be estimated by method.

For current pulses, a Grass CCU 1 constant-current unit was driven by the stimulation apparatus. Both the voltage and current through the stimulation circuit were recorded. The instantaneous voltage at the end of the pulse was measured and divided by the applied current to obtain an estimate of (R_p+R_s). When a voltage pulse was preceded by a

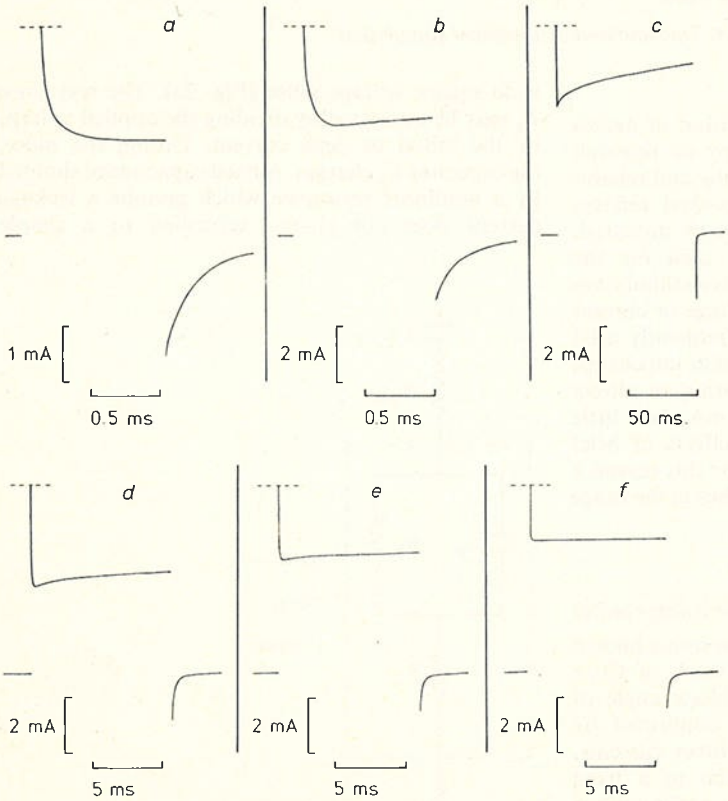

Fig. 2 Current flow during application of square voltage pulses to the intact skin of a subject. Because of the large amplitude, the initial peak current could not be fully shown. In Figs. 2a, b, and c, single pulses were applied. In Figs. 2d, e and f, pulses were applied repetitively with a frequency of, respectively, 1/s, 3·33/s and 20/s

conditioning current pulse, both the output of a constant-current and a constant-voltage device was connected with the electrodes by means of diodes.

The electrodes were two hemispherical nickel-silver suction cups (15 mm in diameter) (WELSH, 1951). They were placed on the skin over the lateral and medial gastrocnemius muscles, their centres 70 mm apart. An isotonic sodium-chloride paste was used as the electrolyte. The effect of the polarisation impedance of the electrode-electrolyte interface on the measurement of R_s and R_p was determined. According to SCHWAN (1966), the polarisation impedance can be expressed as a resistance R_{pol} in series with a capacitance C_{pol} (Fig. 1). R_{pol} and C_{pol} were determined by applying 1 ms wide, square voltage pulses to a circuit consisting of the electrodes connected by an electrolyte bridge. For the range of pulse frequencies and intensities that were used in this study, we found that the capacitive reactance $Xc_{p_{ol}}$ was negligible, so that the polarisation impedance could be equated to a pure resistance (R_{pol}). For pulses of 50 μA, R_{pol} varied from 109 Ω at a stimulus frequency of 0·1 Hz to 107 Ω at 500 Hz. For pulses of 10 mA, R_{pol} varied from 88 Ω (at 0·1 Hz) to 85 Ω (at 500 Hz). In view of these values of R_{pol} it must be concluded that, in our experiments, the values of R_s are subject to a slight, but rather constant, overestimation. The spontaneous potential of the electrode-electrolyte system was 0·4 mV. When the electrodes were placed on the skin the potential was usually about 10 mV.

3 Results and discussion

3.1 *Increase of current intensity during the course of a voltage pulse applied to intact skin*

The method for the estimation of R_p and R_s described earlier was used by LYKKEN (1971). He applied low-voltage pulses and observed that, in agreement with the electrical model, the current flow fell rapidly to a near asymptotic level. In our experiments, using voltage pulses of higher intensity, we found that, following the initial drop, the current flow showed a renewed increase (Fig. 2*b*) and that, even with a pulse duration of 100 ms, it did not fully attain an asymptotic level (Fig. 2*c*). This late increase has also been described by HOZAWA (1928), who observed the phenomenon not only when the voltage of the stimulus was increased but also when the electrical charge transferred by previous pulses was increased. We could measure the current threshold of the late increase most easily when we applied voltage pulses of long duration. For 100 ms pulses, the threshold ranged from 14 to 30 μA. The voltages applied ranged from 5·3 to 18 V. The late increase could also be observed when no electrode jelly was used and therefore could not be ascribed to a change in the electrolyte conductance.

Our observations may contribute to the localisation of the late increase. Constant-voltage pulses of 10 ms duration were applied with a frequency of one per second. With a current intensity of 3·65 mA (chosen for illustrative purposes), the late increase was observed clearly during each pulse (Fig. 2*d*). The increase gradually disappeared with increasing stimulus frequency. The reason for this disappearance was not a decrease of the current intensity at the end of the pulse (which actually increased when the frequency became higher) but was caused by a fading of the current drop occurring after the initial peak current (Fig. 2*e*). With a further increase in stimulus frequency to 20 per second, the current stabilised immediately at its final level (Fig. 2*f*). If the stimulus frequency was then lowered, the process was reversed; the late increase appeared again in its original form and at the original current level.

The late increase could not be ascribed to a change of R_s because the initial peak current remained constant when the stimulus frequency was subsequently increased and decreased. Obviously it was due to an exponential-like decrease of R_p which occurs during the pulse when an electrical charge above a certain threshold value is transferred through the skin. When the current stops, a recovery of R_p occurs so that, at the next stimulus, the late increase will appear again. For the stimulus parameters we used, the time constant of the recovery is such that the recovery may be prevented by applying a new pulse within 50 ms after the previous one. The interpretation that R_p is involved is in accordance with the finding, to be described, that the $C_p - R_p$ network is localised in the stratum corneum. For, when the stratum corneum was removed, the late increase disappeared totally. If the interpretation that the late increase is due to a change of R_p is correct, Lykken's method gives valid information about the instantaneous value of R_p at the end of the pulse. Therefore we used the method in our experiments.

3.2 *Effect of d.c. level on resistance parameters*

When the voltage of the square-wave pulses exceeded a certain threshold, HOZAWA (1928) found a reciprocal relationship between the voltage and resistance ($R_p + R_s$) and reported that crossing of this threshold also entailed what we have called the 'late increase' of current flow during a square voltage pulse. LYKKEN (1971) found that R_s remained essentially constant for pulse voltages which ranged from 0·2 to 10 V. R_p was reasonably constant for pulses up to 2 V, but decreased sharply above 2 V. Because current is a more appropriate parameter to characterise the stimulus intensity than voltage (PFEIFFER, 1968), we investigated the effect of the d.c. level of voltage pulses on R_p and R_s. Pulses varying from 1 to 10 mA d.c. were applied randomly to the untreated skin with an interstimulus interval of 15 s. Each intensity was tested five times. Fig. 3 shows a reciprocal relationship between R_p and the d.c. level. R_s decreased slightly with an increase of the d.c. The peak current intensity ranged from 11·4 mA at 1 mA d.c. to 27·5 mA at 10 mA d.c.

Because LYKKEN (1971) found that removal of the stratum corneum eliminated the $C_p - R_p$ network and reduced R_s by one-third, we repeated our experiment when the stratum corneum had been abraded with emery paper beneath both electrodes. Care was taken that the corium was not injured and that bleeding did not occur. The result was that R_p practically disappeared and that R_s had decreased and was maintained at a constant value of about 480 Ω (Fig. 3). This value has been identified by LYKKEN (1971) as the resistance of the subcutaneous tissues. Using a range of lower d.c. intensities than we did, ROSENDAL (1943) found about the same constant value of R_s in the abraded skin. Using intramuscular electrodes, CRAGO *et al.* (1974) found that the resistance was constant for different d.c. intensities, which is in agreement with the conclusion that, in the treated skin, R_s is localised subcutaneously.

It may be concluded that in the intact skin R_p is

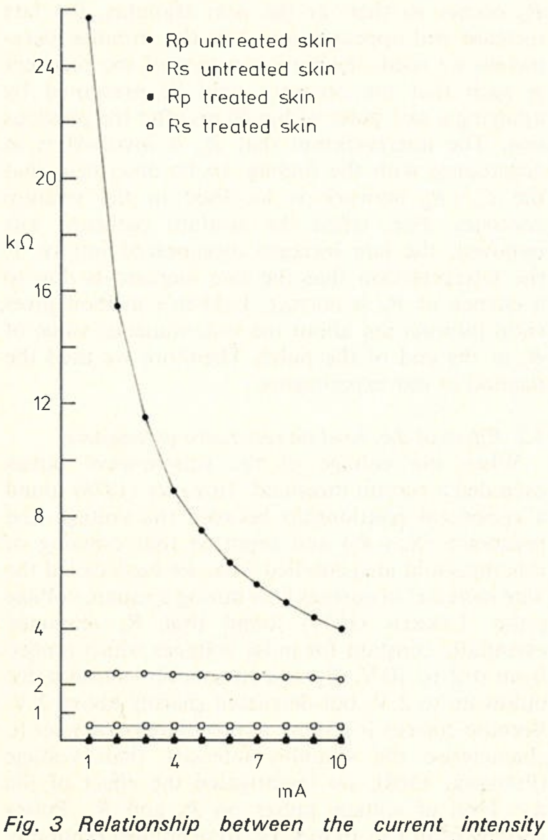

Fig. 3 Relationship between the current intensity (instantaneous current at the end of the pulse) and skin resistance components R_p and R_s when square voltage pulses were applied to intact skin or to skin with the stratum corneum removed

localised exclusively in the stratum corneum and varies with the d.c. intensity. R_s has two components: a major one, which varies with d.c. intensity and is localised in the stratum corneum, and a minor component, which is constant with variation of the d.c. and is found in the subcutaneous tissues.

3.3 *Recovery of R_p after the application of an electrical pulse*

The preceding section showed that the instantaneous fall in R_p at the onset of a voltage pulse is reversible. To investigate the rate of recovery of R_p after the end of the pulse, we measured R_p during a test pulse which was preceded by a conditioning pulse. 12 pulse intervals, ranging from 2 ms to 10 s, were administered randomly. Within such a series of 12 intervals the minimum interval between a conditioning shock (c.s.) and the test shock (t.s.) of the preceding trial was 10 s. Two conditions of c.s. (4 and 10 mA) and four conditions of t.s. (50 μA, 1, 4 and 7 mA) were tested. For each subject, the eight combinations of c.s. and t.s. resulted in eight single sessions. The sessions were carried out randomly with intervals of two days. The random series of pulse intervals was administered three times for each combination of c.s. and t.s. T.S. was a voltage pulse with its intensity adjusted at the onset of each series. To keep the intensity of c.s. constant throughout a series of intervals, a current pulse was used. At the beginning and at the end of each series t.s. only was applied without c.s. to obtain a baseline measurement of R_p and R_s. Means were calculated of these baseline values and of the results of the three trial series.

Figs. 4*a* and *b* show the results for the 10 and 4 mA c.s. conditions, respectively. For all applied combinations of c.s. and t.s., recovery of R_p was a logarithmic function of time. If t.s. was weaker than c.s., R_p was suppressed more than 10 s. For some combinations of c.s. and t.s. (10 mA – 1 mA; 4 mA – 50 μA) it took more than 100 s for a total recovery to occur. Only in the 4 mA–7 mA combination, when t.s. was stronger than c.s., was there a short-term suppressing influence (25 ms) of c.s. on R_p.

Fig. 4 shows that both the level part and the slope of R_p recovery curves were dependent on the stimulus intensity of c.s. and t.s. When the t.s. intensity was increased from 5 μA to 7 mA, there was a decrease in both the level and slope. When c.s. was increased from 4 to 10 mA there was a decrease of level and an increase of slope.

Contrary to R_p which was suppressed by c.s., R_s was temporarily augmented by c.s. above its baseline value. After about 100 ms the effect was no longer seen (Fig. 4).

3.4 *Influence of time on resistance parameters*

Besides the reversible component of the skin resistance decrease, outlined in the preceding sections, there is also an irreversible decrease which is dependent on time. ROSENDAL (1943), DAVIS and KENNARD (1962) and STEPHENS (1963), applying direct currents of low intensity (1 mA), found that the d.c. resistance decreased with prolonged conduction.

We investigated the effect of time on R_p and R_s by administering repetitively constant voltage pulses over 40 min. Different conditions of the stimulus intensity and stimulus interval were tested. R_p and R_s were measured immediately after the electrode attachment and thereafter for successive 5 min intervals. Four stimulus-intensity conditions (1, 4, 7 and 10 mA) were combined with four stimulus-interval conditions (1, 4, 7 and 10 s). Each subject was tested with each of the 16 treatment combinations which resulted. The order of presentation of the combinations was randomised, with intervals of two days between the combinations. The effect of the stimulus intensity and stimulus interval was analysed separately. Fig. 5*a* shows that the absolute reduction of R_p during the 40 min period was considerable and was dependent on the stimulus intensity. The proportional reduction (the reduction as a percentage of the initial resistance) did not vary systematically. Increasing the stimulus intensity from 1 to 10 mA gave results of 62·3, 63·6, 60·3 and 68·4% reduction. Both the absolute and proportional reduction of R_s were positively related to the stimulus intensity. When the intensity was increased from 1 to 10 mA the proportional reduc-

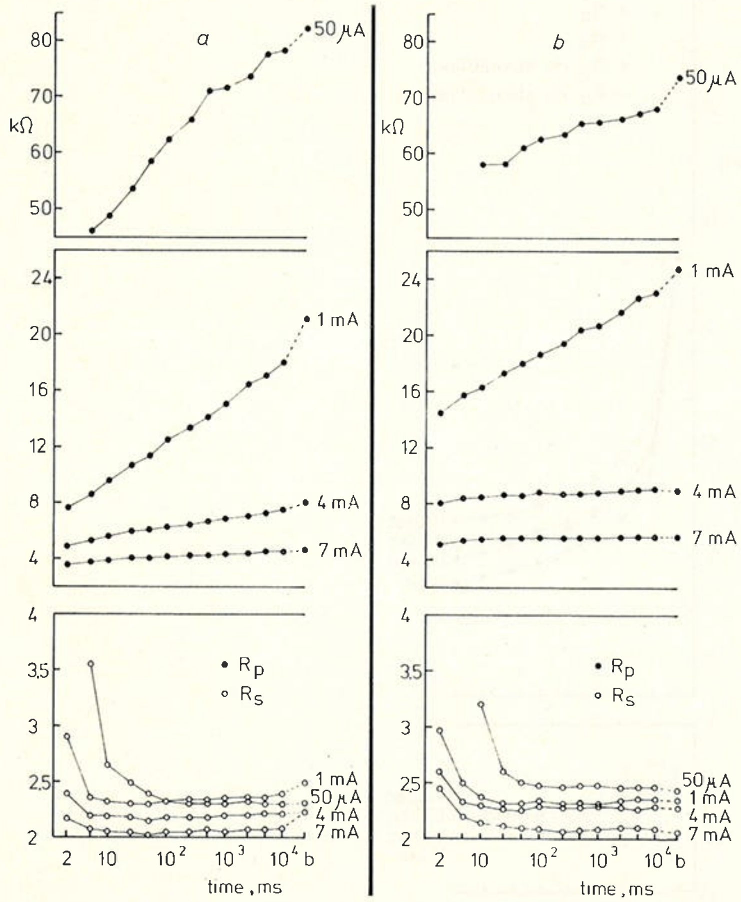

Fig. 4 Recovery of skin resistance components R_p and R_s, measured during a square voltage test shock (t.s.), after the application of a square current conditioning shock (c.s.). (b) Baseline values of R_p and R_s, measured when t.s. was applied without c.s. The curves for the 10 and 4 mA c.s. conditions are shown in Figs. 4a and b, respectively. The intensities of t.s. are indicated in the Figure. For some of the smallest c.s.–t.s. intervals in the 50 μA t.s. curves, the values are missing, because, for this low t.s. intensity, c.s. had a disturbing effect on the measurement of R_p and R_s. In that case t.s. was distorted by the capacitive discharge of c.s. Notice that there are different scales on the ordinate

tion was respectively 11·8, 15·4, 17·3 and 22·7%.

Fig. 5*b* shows that both the absolute and proportional reduction of R_p were positively related to the stimulus frequency. With an increase of frequency from 1 per 10 s to 1 s, the percentage reduction was 55·2, 62·7, 64·5 and 69·7%, respectively. Both the absolute and proportional reductions of R_s were not clearly related to the stimulus frequency. An increase of frequency from 1 per 10 s to 1 per 1 s gave a proportional reduction of 13·3, 17·2, 14·8 and 22·3%, respectively.

From the results in Fig. 3, it is be clear that the decrease of R_p with time is due to changes in the stratum corneum. The decrease of R_s may be due either to changes in the stratum corneum or changes in the deeper tissues. To test this we repeated the 40 min experiment for the 4 mA–4 s treatment combination with the stratum corneum abraded. R_p then remained constant at a near-zero level and R_s had a constant value of about 480 Ω throughout the experiment; thus the change with time was caused by the component of R_s which is localised in the stratum corneum.

When an incomplete portion of the stratum corneum had been removed, as was indicated by some residual differentiation in the current waveform, it was observed that R_p was not completely reduced to zero and showed a recovery with time.

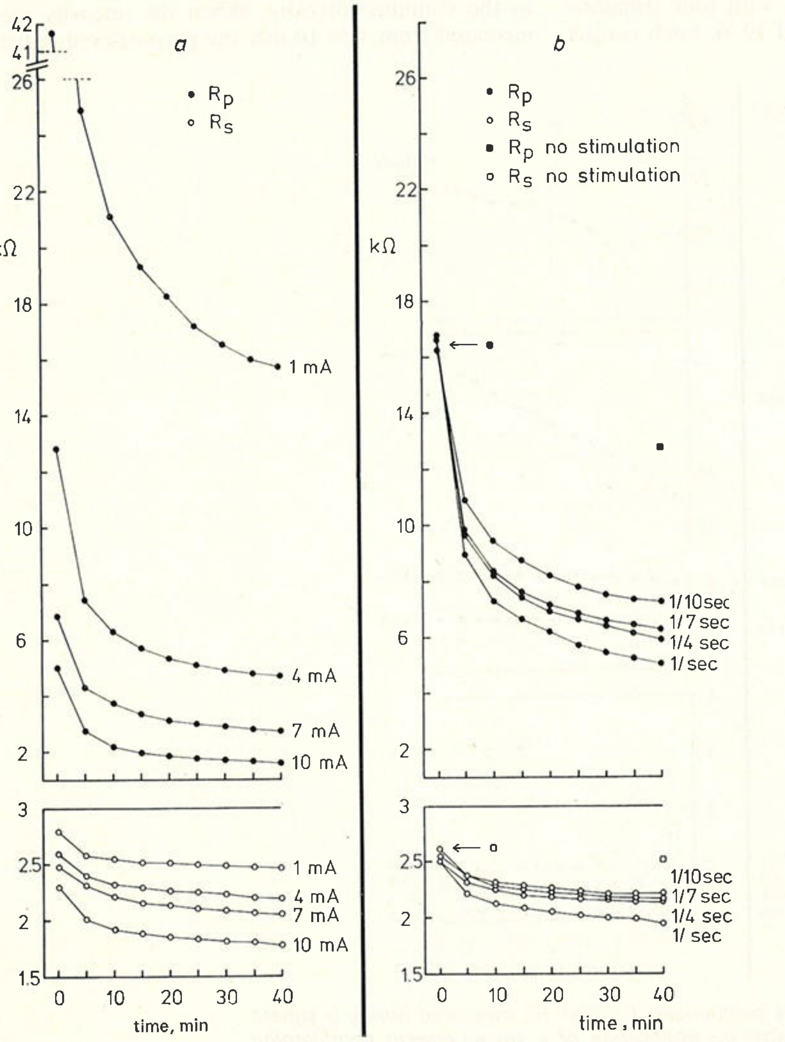

Fig. 5 Relationship between time and skin-resistance components R_p and R_s when repetitive stimulation with square voltage pulses was applied. The influences of stimulus intensity and stimulus interval on this relationship are shown, in Figs 5a and b, respectively. In Fig. 5b the effect of no stimulation for 40 min is also shown. The measurements were made every 5 min. Notice that there are different scales on the ordinate

The recovery could be as high as 140% at the end of the 40 min experiment if it was expressed as a percentage of the initial value. The increase of R_p cannot be explained as the effect of an increase of the skin blood flow which followed on the abrasion, because FRAUENDORF *et al.* (1974) showed that vasodilatation induces a skin-impedance decrease.

We are primarily interested in the variables that influence the proportional reduction of R_p because changes in R_p have great consequences for the total resistance (R_p+R_s), while changes in R_s only have small effects. We saw that the proportional reduction of R_p was not dependent on the stimulus intensity; thus the latter needs no further consideration. The concentration of the contact electrolyte is important because ROSENDAL (1943) showed that increasing it fosters the decrease in resistance. He hypothesised that the decrease in resistance is due

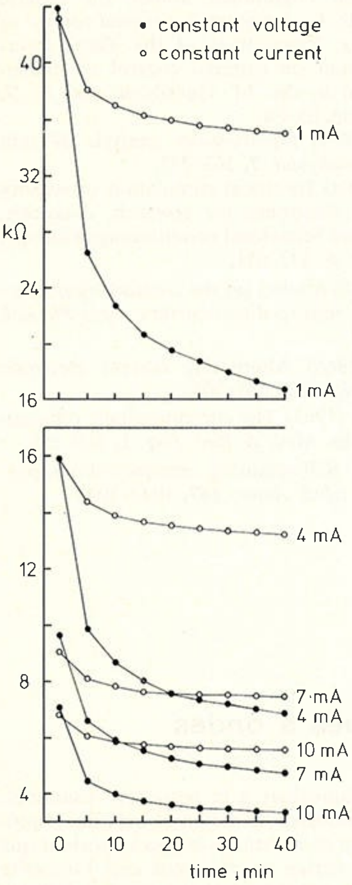

Fig. 6 Influence of time on skin resistance (R_p and R_s) when repetitive stimulation with square voltage or current pulses was applied. Different stimulus intensities were tested. The stimulus interval was 4 s. The measurements were made every 5 min. Notice that there are different scales on the ordinate

to an increase of the electrolyte content of the stratum corneum. STEPHENS (1963) corroborated this by finding that an alternating current of short duration had no influence on the d.c. resistance, while a direct current of short duration diminished the a.c. resistance. He suggested that it is the amount of electrical charge (C/cm^2), transferred through the skin by d.c., which determines the irreversible decrease of the resistance. Our finding that an increase of stimulus frequency strengthened the proportional decrease of R_p agrees with this suggestion. We showed, however, that the decrease was not only due to the effect of current passing through the skin but that it was also partly the result of electrode jelly saturating the skin. When the electrodes were attached but no stimulation was applied during a 40 min period, R_p and R_s showed a decrease of 22·3 and 4·2%, respectively (Fig. 5*b*). These values were much lower than in any of the stimulation conditions.

CAMPBELL and TEGHTSOONIAN (1958) observed in rats, receiving an a.c. to their feet, that a voltage source produced a sharp fall in impedance within 10 min whereas a current source did not appreciably act upon the impedance. An explanation of this difference may be that, in the constant-voltage condition, a decrease of resistance leads to an increase of current which, because of the reciprocal relationship between current and resistance, causes a further resistance drop etc. A process that reinforces itself is initiated, which should not occur in the constant-current condition. We tested this hypothesis by repeating four of the 16 treatment combinations of our experiment (the 4 s stimulus interval combined with each of the four stimulus intensities) with constant-current pulses. The results (Fig. 6) show that in each condition both the absolute and the proportional decrease of (R_p+R_s) is greater for constant-voltage stimulation. The hypothesis is thus supported.

We have previously seen that with constant-voltage pulses the proportional reduction of R_p with time was independent of the stimulus intensity. The same applied for (R_p+R_s) with constant current. For increasing intensities, the proportional reduction was 18·3, 16·8, 17·3 and 18·5%, respectively.

4 Conclusions

When transcutaneous electrical stimulation is used for the purposes outlined in the introduction, the most significant stimulus parameter, the current through the structure to be stimulated, should be adequately controlled. The current intensity of voltage-regulated stimuli, applied to the intact skin, cannot be satisfactorily controlled because of the variations of R_p which are related to a number of factors studied in this investigation. Abrading the skin solves the problem only when it is done so intensively that the stratum corneum is totally removed; otherwise R_p will recover with time and a new instability of current will be introduced. Total removal of the stratum corneum, however, has painful consequences when rather intense stimuli are used; in our opinion this makes this method useless for some of the applications mentioned. It is concluded that current cannot be adequately controlled when voltage or power regulated stimuli are applied to the intact skin. Only current regulated stimuli are suggested for use.

When current regulated stimuli are used, the variations of resistances in series with the structure to be stimulated (e.g. variations in skin resistance) are compensated. By using electrodes with a high impedance, equally distributed over the electrode surface (Kato *et al.*, 1970), the current density should remain equally distributed over the electrode-skin contact area.

A remaining factor which may still influence the current intensity through the target structure (e.g. nerve muscle) is the variability of parallel resistances (other tissues below the stratum corneum). This factor may be of only little importance since subcutaneous tissues may be considered to be practically isotropic. Another parallel resistance is the stratum corneum outside the electrode area. Because of its high resistance, compared to the resistance of the deeper tissues, such a relatively small amount of current will be conducted by it that variations in this resistance will have negligible consequences for the current flow through deeper structures to be stimulated.

References

Barnett, A. (1938) The phase angle of normal human skin. *J. Physiol.* **93**, 349–366.

Campbell, B. A. and Teghtsoonian, R. (1958) Electrical and behavioral effects of different types of shock stimuli on the rat. *J. Comp. Physiol. Psychol.* **51**, 185–192.

Cole, K. S. (1933) Electrical conductance of biological systems. *Cold Spring Harb. Symp. Quant. Biol.* **1**, 107–116.

Crago, P. E., Peckham, P. H., Mortimer, J. T. and van der Meulen, J. P. (1974) The choice of pulse duration for chronic electrical stimulation via surface, nerve and intramuscular electrodes. *Ann. Biomed. Eng.* **2**, 252–264.

Davis, D. R. and Kennard, D. W. (1962) Influence of electric current on the skin. *Nature* **193**, 1186–1187.

Frauendorf, H., Gelbrich, W., Kramer, H. and Reimer, W. (1974) Einfluss von lokaler Erwärmung auf die elektrische und thermische Leitfähigkeit der Haut und das Oberflächen-EMG. *Euro. J. Appl. Physiol.* **33**, 339–346.

Hozawa, S. (1928) Studien über die Polarisation der Haut. I. Die 'Anfangszacke' des elektrischen Stromes durch den Menschenkörper, betrachtet als Ladungserscheinung der Polarisationskapazität der Haut. *Pflüg. Arch.* **219**, 110–140.

Kato, I., Kumamoto, M., Tamura, S. and Tsunekawa, Y. (1970) Human cognitional ability for electric stimulation signals. In *Advances in external control of human extremities*, Proceedings of the Third International Symposium on external control of human extremities, edited by M. M. Gavrilović and A. B. Wilson jr. Belgrade, 69–84.

Lykken, D. T. (1971) Square-wave analysis of skin impedance. *Psychophysiol.* **7**, 262–275.

Pfeiffer, E. A. (1968) Electrical stimulation of sensory nerves with skin electrodes for research, diagnosis, communication and behavioral conditioning: a survey. *Med. & Biol. Eng.* **6**, 637–651.

Rosendal, Th. (1943) Studies on the conducting properties of the human skin to direct current. *Acta Physiol. Scand.* **5**, 130–151.

Schwan, H. P. (1966) Alternating current electrode polarisation. *Biophysik* **3**, 181–201.

Stephens, W. G. S. (1963) The current-voltage relationship in human skin. *Med. & Biol. Eng.* **1**, 389–399.

Welsh, W. (1951) Self-retaining electrocardiographic electrode. *J. Am. Med. Assoc.* **147**, 1042–1044.

Résistance de la peau à des impulsions électriques à ondes rectangulaires de 1 à 10 mA

Sommaire—Plusieurs problèmes concernant un modèle électrique équivalant à la peau sont examinés. Les deux éléments de la résistance pure, dérivables à partir du modèle, ont été testés avec des impulsions électriques à ondes rectangulaires de 1 à 10 mA. L'élément de résistance le plus important que l'on a démontré comme étant localisé dans la couche cornée, variait sensiblement avec l'intensité du courant, l'intensité de l'impulsion précédente et l'intervalle entre les impulsions. Cet élément diminuait avec le temps et cette diminution dépendait de l'importance de la charge électrique transmise à travers la peau. Lorsque des impulsions de tension constante étaient utilisées, cette diminution pouvait être assimilée à un processus se renforçant lui-même. Le plus petit des éléments de résistance n'a montré que des variations relativement peu importantes aux divers paramètres mentionnés plus haut. Il en a été conclu que l'intensité du courant d'une stimulation électrique transcutanée ne peut être contrôlée de manière satisfaisante que si on utilise des stimuli réglés par le courant.

Hautwiderstand unter der Einwirkung von elektrischen Rechteckimpulsen von 1 bis 10 mA

Zusammenfassung—Verschiedene Probleme eines der Haut entsprechenden elektrischen Modells werden besprochen. Die beiden Komponenten des reinen Widerstandes, die aus dem Modell abgeleitet werden können, wurden anhand von elektrischen Rechteckimpulsen von 1 bis 10 mA geprüft. Die größere Widerstandskomponente, die im Stratum Corneum aufgefunden wurde, schwankt merkbar mit der Stromintensität, der Intensität des vorhergehenden Impulses und dem Intervall zwischen den Impulsen. Diese Komponente nahm im Lauf der Zeit ab, wobei die Verringerung von der durch die Haut übertragenen elektrischen Ladung abhing. Bei der Verwendung von Gleichspannungsimpulsen kam die Verringerung einem selbstverstärkenden Prozeß gleich. Die kleinere Widerstandskomponente schwankte nur wenig in Abhängigkeit von der Beschaffenheit der oben erwähnten Stimuli. Man kam zu dem Schluß, daß die Stromintensität transkutaner Stimulierung nur dann gut geregelt werden kann, wenn stromgeregelte Stimuli verwendet werden.