SKIN RESISTANCE CHANGES IN THE LOWER LIMB AFTER LUMBAR GANGLIONECTOMY

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The estimation of sweat gland thermo-regulatory activity has, in the past 20 years, been increasingly utilised, as an objective method of localising and interpreting lesions in the central, peripheral and sympathetic nervous systems. In many cases, such as those of lesions interrupting and limited to the sympathetic pathways, the detailed plotting of anhidrotic skin is the only clinical method available that can accurately outline the cutaneous area affected by the neural section. The revelation of such anhidrotic areas may therefore be used, diagnostically in those rare selective types of trauma, the sympathetic chain stretch injuries described by Guttman, or more commonly, as a means of evaluating the effectiveness and extent of surgical sympathectomies. It is with the disturbances of the thermo-regulatory sweat gland activity in the first 10 days after lumbar ganglionectomy that this paper deals. A new technique for measuring skin resistance changes is also described.

For the measurement of thermo-regulatory sweating in both clinical and physiological practice, two entirely different methods have been developed, the "chemical" and the "electrical."

The former depend on the colour changes resulting from the interaction of the skin surface moisture and a colorimetric substance which has previously been applied to the skin. The original substance used was starch and iodine. This has largely been replaced as a colour indicator by the red-brown dye quinizarin (2-6-di-sulphonic acid). The chemical methods unfortunately have many disadvantages. They all necessitate the heating of the patient sometimes to an uncomfortable degree, in order to exaggerate the contrast between the sweating and non-sweating areas, and in the constitutionally hypohidrotic person, syncope may result before an adequate pattern can be demonstrated. It is not possible therefore to examine patients satisfactorily by this technique within a few days of a major operation. The heating is most suitably done in a special and rather cumbersome sweat cabinet, as reflex thermo-regulatory sweating by immersion of the limbs in hot water will often not reveal the finer details. Heating by ordinary electric lamp cradles is unsatisfactory and may result in burns, especially over anaesthetic areas. The quinizarin powder may be difficult to apply evenly on shiny skin and is always unpleasantly dirty to the patient especially around the head and neck regions, where sneezing or laceration from powder irritation may also invalidate the findings. Finally, the interpretation of the resulting sweat patterns requires meticulous attention to detail and considerable experience.
in the method. Absolute measurements of sweat gland activity cannot of course be made by the chemical techniques.

The electrical methods are based on the finding that the electrical resistance between two skin electrodes varies with the amount of sweat gland activity occurring in the skin under the electrodes.2,10,12,13,14,15,19,20,27,29 The actual distance between the skin electrodes is of little account.

The electrical circuit between the electrodes A and B in contact with the skin may be represented in simplified form by the resistance network shown in Fig. 1. Here R₁ and R₄ represent the contact resistance between the electrodes and the tissue, R₂ represents the resistance between the electrodes at the surface of the skin, and R₃ represents the resistance through the tissues and appears in parallel with R₂. R₃ is small compared with the other resistances and virtually short-circuits R₂. Thus the reading obtained depends on R₁ + R₄, that is, the contact resistance between the electrodes and the skin. This can be demonstrated by a simple experiment.

A subject was chosen whose skin was rather more moist than the average. A disc-electrode ½ inch in diameter was strapped on the forearm just below the elbow, electrical contact being made to the skin through electrode cream. Direct contact with the skin was made at points 1, 2, 3, 4 and 5 inches away from the first electrode through a ½ inch diameter spring-loaded electrode. The resistance between the electrodes was measured by means of a battery and micro-ammeter.

The values obtained in each case lay between 270,000 and 280,000 ohms, which may be regarded as constant within the limits of experimental error, or, in other words, the resistance is not dependent on the distance between the electrodes. Because the thermo-regulatory activity of the sweat glands is dependent on the integrity of their "sympathetic" sudomotor fibres, it follows that "sympathectomised" skin shows a higher electrical skin resistance than normally innervated skin. At a room temperature at 18°C, the difference between the resistance of normal and sympathectomised skin of the average patient is small, the resistance of the sympathectomised being of the order of 10 per cent higher than that of the contiguous normal areas. In the method developed by Richter,31 and later modified by Jasper6 and Whelan and Richter,29 the skin resistance is measured by putting the patient in series with a low voltage (4½–9 volts) battery and a micro-ammeter with a full-scale deflection of 20 microamperes. The indifferent electrode was originally clipped to the lobe of an ear, electrical contact being made with an electrolytic cream; later a simple zinc surface electrode was used. The exploratory electrode consisted of a small plated phosphor-bronze disc attached to a wooden handle. As the resistance over the normal skin was too high to give a meter deflection of enough magnitude, the patient was first heated in a hot-air cabinet until the resistance was lowered sufficiently by
sweating to give an adequate deflection. Then the exploratory electrode was tracked over the patient and when the meter reading fell, owing to contact with high resistance skin, this was assumed to be the "level" of the sympathectomised area.

The advantage of the above direct system of resistance readings over the quinizarin sweat test, is its speed and simplicity of usage but unfortunately it fails to eliminate, because of its insufficient sensitivity, some preliminary heating of the patient. Direct stimulation of sweat gland activity by pilocarpine, mecholyl or furmethide is fallacious. This necessity for heating the patient can be overcome in part by increasing the delicacy of the recording apparatus at the expense of its robustness, or by increasing the amount of current passed through the patient. The latter results in polarization—invalidating the readings—or in unpleasant subjective side-effects to the patient. To obviate this troublesome necessity of heating the patient before testing we have developed the following technique.

For the charting of sympathectomised skin it is not necessary to measure its absolute resistance but merely to demonstrate adequately the boundary zone between it and the contiguous normal skin.

If the patient is made the lower limb of a potential divider circuit as shown in Fig. 2, the output voltage $E_0$ will have the relationship to the input voltage, $E$, expressed by the equation:

$$E_0 = \frac{r}{k + r} E.$$  

This means that the output voltage depends on the patient's skin resistance and will increase with increase of this resistance. Instead of employing a battery for the source of input voltage, $E$, a pulse generator was used. This has two marked advantages, first that subsequent amplification can be accomplished without the necessity for complicated D.C. amplifier systems and secondly that a constant amplitude pulse can be produced relatively easily. The voltage produced across the patient's resistance may be shown diagrammatically in Fig. 3a for "dry" sympathectomised skin and in Fig. 3b for "moist" normal skin.

If the pulse produced as $E_0$ is passed through an amplitude "gate" circuit in which the gate voltage is set at the level shown by the dotted line $g-g$ in Fig. 3a and b, only pulses of greater amplitude than this voltage
will get through the gate. The output from the gate circuit is fed to an amplifier system. After amplification the pulses from the dry and moist areas can be represented diagrammatically by Fig. 4a and b.

The amplitude of the resultant pulses may be evaluated by a peak voltmeter. By choosing suitable circuit constants it can be arranged that the meter reads zero over normal skin and almost full scale over sympathectomised skin. Full circuit and technical data of this electrodematohmmeter (E.D.O.) will be published later.

The electrode was made from a miniature bayonet socket of the type used for indicator lamps. The outer tube with the bayonet locating slots was cut down to a level which left the contact pins protruding for approximately 1/16 inch. The springs on the contact pins were lightened.

For the clinical application of the E.D.O. apparatus, the patient should preferably be tested in a thermostatically controlled room, though many of our early postoperative readings have been done in the ward so that the patient should be disturbed as little as possible. A room temperature of 20–21°C is ideal although in plotting those patients with constitutionally dry skins a few degrees higher than this is advantageous. The area to be investigated is uncovered and left exposed to the room temperature in order to eliminate contact moisture. The electrode is then placed on non-sympathectomised skin—the abdomen in lumbar ganglionectomies—and the circuit adjusted until a zero (no deflection) reading is obtained. Skin readings are then made axially along the limb until the demarcation line between "dry" and "moist" skin is found. This is shown by the needle, which on sympathectomised skin approaches full scale deflection, returning rapidly to the zero position as normal skin is reached. When the rough level is ascertained the whole demarcation zone can be accurately determined. With a little practice and experience, a lumbar ganglionectomy pattern can be "mapped out" in a few minutes.

MATERIAL INVESTIGATED

Twenty-seven patients were investigated; of these 15 had had bilateral and 12 unilateral lumbar ganglionectomies. A total, therefore, of 42 postoperative limb patterns was studied. Table 1 shows the complaints for which the operation was performed and also the sex distribution of the patients.

All the lumbar ganglionectomies were performed by the same surgeon, using an extraperitoneal oblique flank approach. With the exception of the hypertensives (8 cases) and the 1 case of Hirschsprung’s disease, the resected lumbar sympathetic chain was that readily available below the diaphragm and was limited to a segment 2–3” long opposite the body of L3 vertebra.

As Telford has pointed out, “the resection of the trunk cannot be described in terms of ganglia but is best defined as resection of 3–5 cm. centered
opposite the 3rd lumbar vertebra.” This usually involved the removal of two ganglia and intervening chain as judged by the gross anatomy and some were checked by further histological section. It is probable that the ganglia removed by this operation supplied grey rami communicantes to the L2, 3, 4 nerve roots. It is unlikely that the highest lumbar ganglion is removed by this technique as it lies high under the crus of the diaphragm, which must be split by the surgeon for its exposure. The lowest lumbar ganglion (or ganglia) hidden behind the common iliac arteries was not searched for. In the hyper-

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<td>Raynaud’s syndrome</td>
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<td>Embolism (femoral)</td>
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<td>Hypertension</td>
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<td>Obliterative vascular disease</td>
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tensive group, plus the 1 case of Hirschsprung’s disease, a careful dissection was made cephalically, splitting the crus of the diaphragm to include the highest lumbar ganglion in the resection, and occasionally the lowest thoracic when this was present.

FINDINGS

All the findings reported here were made within the first 10 days postoperatively; each case was usually investigated many times on different days within this period. The level of readings on any patient were constant during the period. This is contrary to the findings of Ray and Console, who found the level migrated distally during the immediate postoperative period but seems to be in accordance with most other workers in this field.

The demarcation zone between sympathectomised and normal skin is usually extremely sharp. Occasionally this is not so, and a zone of “intermediate moisture” with a breadth of a few cm. separates the two. More rarely the division is marked by a hyperhidrotic fringe—the so-called “perilesionary” hyperhidrosis. Neither of these variants, when recognised, adds to the difficulty of the investigation.

Within the high resistance area of sympathectomised skin, “oases” of low resistance may survive. The largest detected was about the size of the palm of the hand. They appear to be temporary phenomena and usually disappear within a few days. It is usual for the foot over a “slipper” area (Fig. 5), including the toes, sole, instep, to present immediately postoperatively a low resistance, about equal to that of normal trunk skin at room temperature. This contrasts with the statement of Brown and Adson that “the driest areas occurred in the feet.” As the affected foot is warm to the limit of maximal vasodilatation, of pink colour, and the limb shows a “resist-
ance level,” it may be assumed that the leg has nevertheless been adequately sympathectomised. These “slipper” areas gradually contract in size, disappear after a period of months. We have not seen in our series the onset of gross sweating, colour changes, coolness of the lower (in contrast to the upper) extremity, occurring 3–6 days postoperatively, as described by Smithwick,17 and White and Smithwick.24 That the slipper area is due to spontaneous activity arising in the decentralised sympathetic ganglia would seem unlikely in view of the persistence of this low-resistance phenomenon for many months.

The actual level of skin resistance change varied considerably in the series. Of the 42 limbs examined, 25 were what we have designated a “high” level. A typical example is shown in Fig. 5. The line is sharp and smooth, with no marked indentations or encroachment, running anteriorly just below Poupart’s ligament to the suprapubic region—where it is lost amongst the hair—and posteriorly about the crest of the ilium to the midline. There is a very sharp line of demarcation at the midline with no overlap on either side. There were minor variations in the group but all were essentially this standard pattern when assessment had been made for the anatomical configuration of the patient. All the cases of hypertension (12 limbs) in which, as previously stated, a determined effort had been made at operation to remove the lumbar chain as high as possible after splitting the crus of the diaphragm were included in this group. The remaining 13 limbs had been sympathectomised for conditions other than hypertension and in these the “limited” operation of removing 2"–3" of the chain opposite L3 vertebra had been performed.

In 7 limbs a “low” level was found. Anteriorly the demarcation line ran roughly along the crest of the tibia to below the internal malleolus inferiorly and round the head of the fibula superiorly. On the posterior aspect of the limb these continued upwards to the middle of the sacrum including the posterior lateral aspect of the calf, a strip of the thigh and a disc of buttock in the anhidrotic area (Fig. 6). In all the “low level” group the “limited” operation had been performed.
Finally out of the 42 limbs, 10 were in an intermediate group. The anterior level was not so constant as in the high and low level groups, but fell somewhere on the lower two thirds of the thigh. The whole of the calf and a variable strip of the posterior thigh and buttock were included in the anhidrotic area. Fig. 7 is an example. All the 10 had had the "limited" procedure.

DISCUSSION

To deduce the anatomy of the lumbar ganglionated chain from a basis of cutaneous sweat changes is in our view both fallacious and profitless. The anatomy of the chain is extremely variable,1 and the distribution of the grey rami bewildering in its complexity. Its diameter may vary from a fraction to several mm., it may be single or duplicated, the number and position of its ganglia are variable and their connections are notoriously inconstant. Occasionally the whole chain may be a diffusely ganglionated mass, without visible intervening thinning. It is justifiable to infer, however, from our findings that in those ganglionectomies in which an effort is made to extend the resection up behind the crus of the diaphragm, the whole of the lower limb will show skin resistance change and may be presumed to be completely sympathectomised, whilst in those in which a segment of the chain opposite L3 vertebral body is removed a variable pattern, unpredictable within wide limits, will be encountered. This accords with the reports of Smithwick,16 Richter and Woodruff,13 List and Peet,7 Fontaine, Houot and dos Santos,5 who consider that the highest lumbar ganglion should be removed if it is wished to denervate the upper thigh area. In striking contrast is the statement of Ray and Console,9 "Complete denervation of the lower extremity, therefore, is not determined by preservation or removal of L1 ganglion or any part of the paravertebral ganglionated chain above it." Ulmer and Mayfield,22 have gone so far as to suggest that the removal of the lower thoracic ganglia may be necessary in addition to the resection of the lumbar chain, in order to guarantee a high thigh denervation. With this we would most strongly disagree. In those hypertensive patients who have had the thoracic sympathetic chain removed following a previous high lumbar ganglionectomy, no increase in the area of high electrical skin resistance has been found.

This question of high thigh denervation is not a matter of purely theoretical importance. For in those cases of arterial disease in which the thrombus extends into the common femoral region, it is imperative to ensure the maximal collateral dilatation in the region above the block. This can be obtained, it would seem, only by including the retrocrural sympathetic chain in the resection. A sympathectomy that dilates only the collateral circulation distal to the arterial block may be causing a proportionately greater shunting of the limited blood supply through the skin of the distal limb, and thus impair rather than benefit the general limb nutrition. We therefore feel from the evidence available both in the literature and from our own findings that in cases of arterial disease involving the thigh a "lum-
bar” sympathectomy should include the highest lumbar ganglion, which can only be regularly performed after the splitting of the diaphragmatic crus. It should be stressed that in the whole of the limbs examined in this series the foot has been sympathetically denervated as shown by colour and temperature change. The levels found by our technique in this series have been checked in many cases by the more established methods of Richter and by the quinizarin sweat test and similar results obtained, although the “oases” and “slipper” areas were not adequately demonstrated.

SUMMARY

1. Methods of detecting sudomotor fibre interruption are discussed.
2. A new technique for the investigation of sympathectomised skin is described.
3. Patterns of high skin resistance after 42 lumbar ganglionectomies are described. It is shown that the highest lumbar ganglion must be removed if the upper thigh is to be surely denervated.

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REFERENCES

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