CUTANEOUS AREAS DENERVATED BY UPPER THORACIC AND STELLATE GANGLIONECTOMIES DETERMINED BY THE ELECTRICAL SKIN RESISTANCE METHOD*

CURT P. RICHTER, Ph.D.
Psychobiological Laboratory, Phipps Psychiatric Clinic,
The Johns Hopkins Hospital, Baltimore, Maryland

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In previous studies the electrical skin resistance method was used to outline the areas of skin that became denervated by lumbar and thoracolumbar sympathectomies.6,9 In the present study this method was used to outline the denervated areas in patients with upper thoracic and stellate ganglionectomies.

Observations were made on 31 patients with a total of 51 sympathectomies. Forty-five of the operations were upper thoracic sympathectomies, 6 were stellate ganglionectomies. Five different operations for upper thoracic sympathectomies were used. Most of the latter were performed in the treatment of vascular disturbances of the hands, while most of the stellate ganglionectomies were performed in the treatment of migraine headaches and vascular disturbances of the eyes.

In the present study an effort was made to determine: (1) the consistency with which the various operations denervate (a) the hands, (b) the face; (2) the constancy of the areas that become denervated by the sympathectomies; (3) the ganglion or ganglia that appear to play the most important part in the denervation.

METHODS

The dermometer and the technique used to outline sympathectomized areas of skin have been described in detail in previous papers.6,7,9 Areas of skin deprived of sympathetic innervation display elevated electrical resistance to a small direct current. With the dermometer such areas may be mapped by punctate exploration of the skin. The instrument is used simply to show differences in skin resistance levels rather than to obtain actual quantitative measurements of skin resistance. Since this resistance varies inversely with sweat-gland activity, heating the patients for a few minutes in a hot-air cabinet before the examination greatly reduces the resistance of normally innervated skin and thus enhances the contrast between normal and denervated areas.

The borders of the areas of high skin resistance are marked on the skin with a black skin pencil and later copied on charts showing the front, back and side views of the head and body; also, photographs are obtained of the same views.

For this study we used only the records that we obtained during the patient's stay in the hospital (in most instances 12 days after operation). Records obtained over longer postoperative intervals will be reported in a later study on regeneration.

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The usual upper thoracic preganglionic sympathectomy as recommended by Smithwick\textsuperscript{11} for the denervation of the hands was performed on 15 patients with a total of 29 operations. In brief, the chain was sectioned below the 3rd ganglion; all the rami from the 2nd and 3rd intercostal nerves were cut; and the proximal end of the chain, after being lifted up out of the opening, was sewed into a muscle. Approximately 1½ inches of the 2nd and 3rd intercostal nerves, including, usually, the posterior ganglia, were resected; the dorsal and anterior roots were sectioned intradurally in some cases; in others the anterior root was sectioned in its intradural portion. None of the sympathetic ganglia were removed. The underlying physiology of this preganglionic operation was worked out by White, Okelberry and Whitelaw.\textsuperscript{12}

In 3 patients the 2nd and 3rd ganglia were bilaterally removed by the dorsal approach, after resection of the 2nd and 3rd ribs. No intercostal nerves were cut.

In 1 patient, only the 2nd thoracic sympathetic ganglion was removed, as recommended by Goetz and Marr\textsuperscript{4} to denervate the hands. This extirpation was accomplished through the dorsal approach after the resection of about 3 inches of the 3rd rib, as well as of a portion of the transverse process of the vertebra. Both the anterior root and the sensory root of the 2nd nerve were cut, and a small part of the nerve, including the sensory ganglion, was removed. The rami to the sympathetic chain above and below the 2nd ganglion were severed and the ganglion was removed.

The first 4 thoracic sympathetic ganglia were removed in 3 patients with a total of 5 operations by the transthoracic route first used by Goetz and Marr\textsuperscript{4} and modified by Longmire (unpublished). The chain was exposed through an incision made anteriorly in the 2nd or 3rd intercostal spaces. The 4 ganglia were removed along with portions of the 2nd and 3rd intercostal nerves, including the dorsal spinal ganglia.

The 1st, 2nd and 3rd ganglia were removed in 3 patients by the dorsal route in the course of an operation for removal of the pulmonary plexus, recommended by Rienhoff and Gay\textsuperscript{5} in the treatment of asthma. After resection of about 4 inches of the 4th or 5th rib the lung was collapsed; all connections between the lungs and the vagus nerve were severed and the 3 sympathetic ganglia were removed.

The stellate ganglion was removed in 6 patients by the cervical route through an incision made in the neck about 2 cm, above the clavicle, according to the technique of Jonnesco.\textsuperscript{4}

Fourteen surgeons in the Department of Surgery of The Johns Hopkins Hospital performed these operations over the course of a 5-year period.

**RESULTS**

Fig. 1 shows the skin areas that were affected by the various upper thoracic sympathectomies. Shading indicates areas of relatively high electrical skin resistance, or denervated areas. This figure lists the different operations and the number of times each was performed (unilaterally). The total number is then broken down to show which skin resistance patterns resulted from each operation and how often.

1. **Removal of the Upper 4 Thoracic Ganglia (Transpleural).** Out of 5 operations, 4 denervated the largest area, marked “1,” in Fig. 1. This area included the entire arm, half of the head, neck and chest down to a level just below the nipple. The remaining operation denervated the small area marked “6.” The surgeon apparently did not remove all of the chain in this last operation.

It should be noted here that the removal of these 4 ganglia, and, in fact, most of the following operations, elevated resistance on the central parts of the face less than it did on the arm, chest and neck. This relative immunity of the face to sympathetic denervation is discussed below in the section on facial patterns.
II. Removal of the 2nd and 3rd Thoracic Ganglia. In 5 out of 6 operations the removal of the 2nd and 3rd thoracic ganglia by the dorsal route denervated the pattern marked “2” in Fig. 1. This pattern is the same as the one that resulted from the removal of the upper 4 thoracic ganglia except that it extended only to a level of approximately 1 inch above the nipple. The remaining operation produced the pattern marked “3,” which did not include the face and neck.

III. Preganglionic Isolation of the 2nd and 3rd Ganglia. This operation, which was performed a total of 29 times, denervated the pattern marked “2” with great consistency; namely, in 27 of the 29 operations. In 2 instances the pattern marked “3,” sparing the head and neck, was found (see Fig. 1).

IV. Removal of the Upper 3 Thoracic Ganglia. The upper 3 thoracic ganglia were removed incidentally to pulmonary plexus extirpation in 3 operations with variable results. One of the operations denervated the area marked “1”; a second, the area marked “2”; and a third, the area marked “3” (see Fig. 1).

Thus, removal of the upper 3 thoracic ganglia, or of only the 2nd and 3rd ganglia, or simply preganglionic isolation of the 2nd and 3rd ganglia, all denervated essentially the same area of skin.
V. Removal of only the Second Ganglion. In 1 patient, only the 2nd ganglion was removed, bilaterally. On both sides, removal of this ganglion denervated the pattern marked "3," which included the arm, shoulder, and half of the chest from a level of 1 inch above the nipple to the line of the clavicle, but it did not denervate the face and neck (see Fig. 1).

VI. Removal of the Stellate Ganglion. Six stellate ganglionectomies denervated 4 different skin areas: the pattern "2" in 1 patient; the pattern "4" in 2 patients; the pattern "5" in 1 patient; and the pattern "6" in 2 patients. The lower borders of these 4 different areas clearly followed the outlines of the sensory dermatomes (see Fig. 1).

Facial Areas of Relatively Low Electrical Skin Resistance Remaining After Upper Thoracic Sympathectomies

While mapping the regions of high resistance that resulted from upper thoracic sympathectomies, we found that in most individuals the central portions of the face had somewhat lower readings than those on the surrounding areas but not as low as those obtained in normal individuals, while in others it was quite as low as is found in normals. Otherwise, these regions of intermediately high resistance proved to correspond closely, in shape, size and location, to the patterns of low skin resistance found under ordinary conditions on the normally innervated face.5 The top row of heads in Fig. 2 shows several such facial areas of low skin resistance in normal individuals. Although under ordinary conditions these facial areas remain quite constant,
they undergo marked changes, particularly in relation to external and internal temperature and to sleep. Thus, in a cold environment and during sleep, these areas constrict until they include scarcely more than a narrow band around the mouth (see Fig. 2, "4"), while in a hot environment or during excitement they dilate to include the entire face, parts of the neck, or even the entire head (see Fig. 2, "3").

The facial area of intermediately high or normally low skin resistance, which was found most frequently in patients with the typical Smithwick operation, is shown in Fig. 2, "5." The following two heads, "6" and "7," show 2 larger facial areas which were found in patients with the upper thoracic sympathectomies (removal of T-2 and T-3). The stellate ganglionectomies produced either no facial areas of low resistance at all or only a small area (see "8"). Some patients with upper thoracic sympathectomies showed very irregular and often asymmetrical facial patterns, even though supposedly exactly the same operation had been performed on both sides.

**Axillary Areas of Low Electrical Skin Resistance Remaining After Upper Thoracic Sympathectomies**

The axillae in individuals with normally innervated skin show well-defined areas of low electrical skin resistance. These axillary areas appear to change with relation to external and internal conditions just as the facial areas do. They decrease in size in cold temperature, expand in warm temperature. Their relation to the distribution of the apocrine glands in the axillae has not been established.

In most instances these areas of low resistance disappeared completely after upper thoracic sympathectomy. However, a small number of patients showed them quite as clearly as they appear in individuals with a normal innervation of this region. Fig. 3 shows the record of one of these patients with a Smithwick sympathectomy.

**Relation of the Areas of High Electrical Skin Resistance to Areas That Do Not Sweat**

In over one fourth of the patients examined, areas of high electrical skin resistance were compared with areas that did not sweat, as determined by the Minor starch-iodine test. The sweating test was made immediately after the completion of the skin resistance test while the black outlines of the areas of high resistance were still present on the skin. The patients were allowed, however, to cool off before application of the starch-iodine mixture and subsequent reheating. The areas that showed a very high resistance (that is, failed to move the galvanometer needle at all) corresponded very closely with the areas that did not sweat; while the areas with a very low resistance (that is, which gave a full deflection of the galvanometer needle) corresponded with the areas that showed active sweating.

Fig. 4 shows the areas of high electrical skin resistance and areas of non-sweating as determined by the Minor starch-iodine test in a patient with a
unilateral stellate ganglionectomy. The boundaries of the two areas coincided almost perfectly throughout.

*Constancy of Areas of High Electrical Skin Resistance*

The areas of high electrical skin resistance were outlined on several days, usually within the first 10–15 days postoperatively. In the absence of regeneration of the sympathetic nerves, the areas remained constant from day

![Diagram](image-url)

**Fig. 3.** Drawing showing axillary area of intermediately low resistance that remained within boundaries of sympathectomized region in a patient after a standard Smithwick sympathectomy.

![Images](image-url)

**Fig. 4.** Photographs showing the close correspondence between areas of high electrical skin resistance (black lines and letter "H") and nonsweating areas (Minor starch-iodine test—not black) in a patient with a stellate ganglionectomy.
GANGLIONECTOMIES EXAMINED BY SKIN RESISTANCE

to day, except occasionally during a prolonged hot spell in the summer, when they became smaller.

As an exception to this general rule, several patients for 3 to 15 days postoperatively showed temporary areas of abnormally low rather than very high skin resistance. In some of them these areas of decreased skin resistance were identical in shape, size and location with the usual areas of increased skin resistance that are produced by upper thoracic sympathectomies, and which actually were ultimately obtained in the same patients. Fig. 5 shows the skin resistance patterns for one of these patients at various intervals after a typical Smithwick sympathectomy was performed on Dec. 5, 1942, on the right side, and 11 days later on the left side. On December 9th when the patient was examined at room temperature the resistance of the skin over the area that usually becomes denervated by an upper thoracic sympathectomy had a resistance which was lower than that of the skin on the rest of the body. This type of record indicates hypersympathetic activity. Heating the patient in a hot-air cabinet reduced the resistance evenly over the entire body. On the following day, December 10th, the patient gave essentially the same record except for the appearance on the operated side of an additional area of abnormally low skin resistance over the lower thoracic

Fig. 5. Chart showing temporary reversal of areas of high electrical skin resistance observed successively after sympathectomies on the right and left sides. Diagonal lines indicate areas with a very low resistance; dark dotted areas indicate the very high electrical skin resistance that characterizes complete sympathetic paralysis.
region. (The possible significance of this area will be discussed below.) On December 11th when examined at room temperature the patient showed a high skin resistance over the entire surface of the body. When heated in the hot-air cabinet the resistance dropped to a low level on all parts of the body except over the right arm, shoulder, and part of the chest (dark black stippling). On December 12th, the 7th postoperative day, the patient again showed no areas of low skin resistance at room temperature. After a few minutes in the hot-air cabinet the area of high skin resistance that now remained was larger and typical of areas that become denervated by upper thoracic sympathectomies. For the next few days he continued to show the same record.

On December 16th an upper thoracic sympathectomy was performed on the left side. When examined on the following day in the heat cabinet the areas of high resistance had patterns typical of bilateral upper thoracic sympathectomies. On December 18th the resistance was low on the inner surface of the right arm, that is, on the previously operated side. On December 19th the resistance had dropped to a low level also on both sides of the face, on part of the chest, and over the entire surface of the left arm. On December 21st, 22nd and 23rd all of the head and neck showed a low resistance. On December 29th, the 13th postoperative day, the area of high resistance included all of the head, neck, chest and both arms and thus showed a typical upper thoracic pattern.

On the days when the resistance dropped to low levels over parts of the sympathectomized area, the patient and the ward physician noticed the presence of sweat over these parts.

Many neurosurgeons have noted this phenomenon of temporary sweating, which usually occurs from 3–5 days postoperatively, but the phenomenon remains unexplained. The clinical history of the patient whose records are shown in Fig. 5 may provide an explanation. During most of the postoperative period when sweating or low skin resistance were present, body temperature was elevated (99°–102°). Immediately after the 1st operation the patient complained of a marked pain in the chest, and after the 2nd operation active pneumonia was discovered, which may have been present also after the 1st operation. Treatment with sulfadiazine, started 2 days after the 2nd operation, caused body temperature to drop to normal again.

The presence of lung infection or pleurisy may account for the small area of low skin resistance that appeared over the thorax on the 5th day after the 1st sympathectomy in this patient. Similar isolated areas of low skin resistance have previously been found on various parts of the thorax in patients with pleurisy and lung infections.

Relation of the Areas of High Electrical Skin Resistance to Areas of Anesthesia in Patients with Resection of One or More Intercostal Nerves

The 2nd and 3rd intercostal nerves were resected in all of the Smithwick operations and in a few of the others. In the 7 patients that were examined,
well-defined areas of partial or complete anesthesia to pin prick were found. Fig. 6 shows a typical record of one of the patients with a Smithwick sympathectomy. The lower border of dullness (crosses) corresponded closely with the lower boundary of the area of high electrical skin resistance (continuous line), while the upper border was included within the area of high skin resistance.

![Diagram of areas of anesthesia](image)

**Fig. 6.** Drawing showing outlines of areas of partial anesthesia (crosses) and lower border of a typical denervated area produced by Smithwick sympathectomy (solid black line).

Several of these patients complained of numbness and discomfort over the chest or particularly under the arms. In all instances the areas of discomfort or pain coincided closely with the areas of partial or complete anesthesia to pin prick. The section of the 2nd and 3rd intercostal nerves must in some unaccountable way produce these effects. Blades and Dugan in their operations on the chest for war wounds made similar observations. They found that section of the intercostal nerves produced areas of numbness and chronic pain and that these areas showed a very high electrical skin resistance.

The areas of high skin resistance did not depend on the resection of the intercostal nerves, as is shown by the fact that essentially the same skin...
resistance patterns were obtained when the 2nd and 3rd ganglia were removed without resecting the 2nd and 3rd intercostal nerves.

DISCUSSION

The observations reported above indicate occasional variations in the results of the different types of operations. This is well demonstrated by the results of the removal of the upper 3 thoracic ganglia, which in 3 cases produced as many patterns. There are also marked inconsistencies when the results of one operation are compared with those of another. For example, one operation reported as a simple stellate ganglionectomy produced a pattern of elevated skin resistance typical of that produced by the Smithwick operation. The remainder of the stellate ganglionectomies affected only part of the arm. In one case, reported removal of the upper 4 thoracic ganglia produced a pattern less extensive than that found in other cases following removal of the 2nd ganglion alone. These obvious inconsistencies may be explained by the anatomical complexities of the sympathetic chain, which make precise identification of ganglia difficult, and by inconsistent operative procedure. (The identification of the stellate ganglion offers particular difficulty because it displays great variation in size, shape and location.) This being the case, the skin resistance technique becomes a valuable aid to the neurosurgeon since it provides a simple, objective check on the effectiveness of the operation.

Because of this variability in operating procedure, little can be said about the thoracic dermatomes until a larger series of cases has been studied. Then the patterns corresponding to the various ganglionectomies can be determined on a statistical basis. Of the 6 operations studied, the Smithwick operation is the only one in which a sufficient number of cases has been collected to draw any conclusions. It is noteworthy that the lower border of the chest pattern found in 27 out of 29 cases corresponds well with the lower border of the 3rd thoracic dermatome as determined by other methods.

The observations show that the several types of upper thoracic sympathectomies denervate their objectives, the arms and hands, with a high degree of consistency. Of the 45 upper thoracic operations, only one failed to produce elevated skin resistance patterns involving the entire arm and hand. Considering the range of operative procedures, these results suggest that one or more ganglia removed in common by all the operations is responsible. The only ganglion removed in all the operations was the 2nd thoracic. It is perhaps significant that, in the patient in whom only the 2nd ganglia were removed, the denervated areas included both arms and hands. This is in agreement with the reports of Goetz and Marr. Also the sparing of the head by the removal of the 2nd ganglion alone supports the view held by Foerster and Goetz and Marr that the face does not receive any innervation from the 2nd thoracic ganglion.

The present results suggest that upper thoracic sympathectomies do not completely denervate the facial region, since in many instances the eyes,
Ganglionectomies examined by skin resistance

nose and mouth showed only partial denervation. Even a stellate ganglionectomy does not always elevate the resistance in these areas. An explanation of these findings is not yet available. Information regarding the nerve supply to the so-called “facial area” of low electrical skin resistance in individuals with normally innervated skin may shed some light on this problem.

It is noteworthy that in all instances the borders of the sympathectomized areas closely followed the outlines of the sensory dermatomes on the face as well as on the arms and thorax.

SUMMARY

1. Denervated areas of skin were outlined with the electrical skin resistance method in 25 patients with upper thoracic sympathectomies and in 6 patients with stellate ganglionectomies. Five different types of upper thoracic sympathectomies were included, involving different approaches and the removal of different ganglia.

2. Almost all types of upper thoracic sympathectomies denervated the hands. Only 6 out of the 51 operations failed to fully denervate the hands.

3. Very few of the upper thoracic sympathectomies or stellate ganglionectomies fully denervated the face. In most instances the central part of the face, which normally showed a low skin resistance, showed only a small increase in skin resistance or none at all.

4. The stellate ganglionectomies showed the widest range of variation in the areas that they denervated.

5. The successful denervation of the hand appears to depend largely on the removal of the 2nd thoracic ganglion since all operations which denervated the hand included this ganglion and since in two instances the removal of this ganglion alone fully denervated the hands.

6. The patterns of high electrical skin resistance remained quite constant from day to day, except in a small number of patients, who showed temporary patterns of abnormally low rather than high skin resistance patterns over denervated areas. The outlines of these hyperactive areas coincided exactly with the denervated areas that were found later in the same patients.

REFERENCES


