OBJECTIVE METHODS FOR DETERMINING THE FUNCTIONAL VALUE OF SENSIBILITY IN THE HAND

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It has been borne home to me with the passage of the years how little the results of the customary tests of sensibility in an injured hand correspond with the actual ability of the patient to use his hand. When one wishes to study cutaneous sensibility from the point of view of function, little is gained by analysing the different modalities. What is desired is the answer to these questions: 1) which of its many tasks can the hand do with the sensibility remaining? and 2) is the lost sensibility returning?

In Sweden persons receiving workmen's compensation generally return for re-examination every year or so for a long time to have their compensation adjusted, and I have taken this opportunity of making a systematic analysis of the value of the customary tests for judging sensibility.

Partly for this purpose, I have worked out a new functional test for examining the sensibility in an injured hand—that is, a hand with enough motor function to make its sensibility of use. I have called it "the picking-up test," and it is illustrated in Figures 1 and 2. The subject is asked to pick up a number of small objects on a table and to put them as quickly as he can into a small box, first with one hand and then with the other. After he has done this a few times he is asked to do the same thing blindfolded. It is then studied how rapidly and efficiently he picks up the objects; comparison is made between his right and left hands, and likewise between his performance when he is blindfolded and when he is not. The test with blindfolding can be made harder by asking him to identify the objects as he picks them up. If his hand possesses normal sensibility, it can "see" even when the subject has his eyes closed. If sensibility in the median nerve region is impaired, the subject grasps the objects with the thumb and the ring and little fingers (Fig. 2) instead of with thumb and forefinger as he normally would.

I compared the results of this test and of others with the results of currently used tests for sensibility in a number of cases with good motor function but with reduced sensibility in the median nerve area.* The result was astonishing. Most of the current methods proved

* A study to be published elsewhere.
of no value for judging the cutaneous sensibility from the point of view of function. The tests with cotton wool and pins for touch and pain, and the ordinary methods for testing the sensations of warmth and cold and deep pressure, were clearly not satisfactory for estimating the functional loss. On the contrary, these methods were apt to be misleading, for one is
prone to believe that a hand that shows a normal or low threshold for touch and pain must also have sensibility of comparable functional value. The fact is, however, that even when it does, and even when it has normal motor function, it may still be quite unable to do the everyday tasks requiring precision—to perform what I have called a precision-sensory grip (Figs. 3 and 4)—and so be greatly disabled.

The only two of the earlier methods that gave useful information about the functional value were Weber's two-point discrimination test and Seddon's coin test. These methods, however, have the disadvantage that they are subjective, and the results depend largely upon how much the examiner and patient are able to concentrate. They are apt to give a false impression, especially if the patient lets himself be influenced by hopes of remuneration. Moreover, they are of no use when the patient is very young, feeble-minded or unable to co-operate for some other reason.

It seemed essential, therefore, to find an objective method of testing sensibility. I observed that an area of skin in the hand which lacks tactile gnosis* also lacks the ability to perspire. Bunnell (1944) wrote: "The skin in an anaesthetic area is so characteristic that one can, by feeling with the finger, determine the area almost as accurately as by testing with an applicator. The finger glides over it smoothly with a satiny feel; it does not jump along as it does on normal skin, in which the sweat glands are working. Atrophic skin appears smooth." Since an applicator cannot be used to differentiate between good and defective tactile gnosis, it is in fact far less exact than the palpating finger.

In my series it was possible to see changes in an area of defective sensibility with the naked eye. Thus it could be seen that the pulp was atrophied, the ridges were more or less eradicated and the colour was changed.

It should be noted that these changes were seen in every case in which tactile gnosis was lacking, provided there was not too much fibrous induration or scar formation. Richards (1954) did not always find trophic lesions of this kind in cases of war injuries in which the sensory innervation was lost, but this was probably because in his cases the picture was frequently confused by scars and other complications.

It is known that, when a sensory peripheral nerve is severed, the skin in the involved region becomes dry only a few minutes afterwards (Richards 1954). The sweat glands stop functioning entirely. I have often observed how rapidly this phenomenon sets in. On the other hand, an area that has sudomotor function and feels moist also has tactile gnosis, apart from the exception to be described later. My experience that the loss of tactile gnosis could be established by palpation formed the background of my attempts to find a method to register the sensibility in the hand objectively, without the co-operation of the patient. In order to be able to assess the results objectively a method of registering the changes had to be found, as palpation is a subjective method of examination.

My first attempt to register the changes in skin areas with defective sensibility was based on fingerprints. I found that it was often possible to map out atrophied areas in the pulp and defects in sensibility with the ordinary fingerprints used for identification. Thus atrophy of the pulp caused the lines of the fingerprint to come closer together, crowding a greater number of lines into a given space. The lines also tended to disintegrate into points. New wrinkles crossing the lines appeared. These changes have apparently never been described in criminological literature, and they proved to be of interest in those circles. However, they do not become manifest until some months after the nerve injury. There proved to be better

* The terms used for this function are both ambiguous and inexact. Here is not a question of the known modalities of sensibility. It is not certain that the sum of these modalities is equal to the total sensibility. The term "skeognosis" is often used in the literature on hand surgery, but in neurological literature it is used for a central function. It is not advisable, therefore, to use it for a constellation of peripheral sensory factors. Moreover stereognosis is not a wide enough concept. Here it is a question of the complex sensibility that gives the grip "sight." For these reasons I have chosen the term "tactile gnosis" (Broman 1945). Tactile gnosis should not be confused with tactile sensibility, a term used for the simple appreciation of touch.
A gross grip may be useful with a lower degree of sensibility than needed for the precision-sensory grip, but cannot be executed with normal speed and skill.

FIG. 4

A gross grip may be useful with a lower degree of sensibility than needed for the precision-sensory grip, but cannot be executed with normal speed and skill.
ways of registering denervation in the skin objectively, based on the changes in sudomotor function between areas with normal and damaged sensibility.

It is no means a new procedure to register cutaneous sensory loss by demonstrating changes in the sudomotor activity. Three different lines have been followed.

1. Dye tests have been used for many years to study the secretion of sweat. In most of them the skin is first coated with the dye and the patient is made to sweat either with the aid of heat or with different drugs. When sweating sets in, the areas with normal sudomotor function become coloured while the others remain unchanged. Minor (1928) described a method in which the skin was painted with a suspension of iodine and starch in oil. His test has been widely used, but not for testing the sensibility in the fingers and hand. Dorscheid (1954) tried to show hyperhidrotic variations in hand sweating in psychiatric patients with this method. In 1940 Guttmann described a new method using quinizarin. This method has been widely used for testing the extent of sensory loss in large areas of skin. However, it has the disadvantage that the dye is apt to spread about over the patient and the room in which the tests are made. It also causes the patient great discomfort as he has to be kept for some time in a hot chamber. Seddon, Medawar and Smith (1943) used Guttmann's method to follow the degree of "academic recovery" after nerve suture—that is, the restoration of sensibility as shown by neurological methods. To their disappointment, however, they found that the method was "erratic, and therefore quite useless for the estimation of rates of regeneration." Klar (1955) and others have used essentially the same method for diagnostic purposes but not in the hand.

2. It has been known for some time that denervated dry skin and normally moist skin differ distinctly in electrical resistance. The study of this phenomenon, called dermometry, was again popularised by Richter and Katz in 1943. As a rule, they observed a sharp borderline between normal and abnormal regions. Their method has the advantage that it can be used for smaller surfaces than the aforementioned dye tests because there is not the same risk of contamination between perspiring and dry areas. It can also be used when it is difficult to get the patient to cooperate—for instance, for children and in the region of an open wound. Seddon (1954) pointed out that the electrical method of examination is less sensitive than Guttmann's dye test because it is unable to show the pin-point perspiration that may be a sign of an incomplete lesion or incipient recovery.

3. Kahn (1951) showed that one could differentiate between denervated and normal regions by examining them under the microscope after the patient had been made to sweat profusely.

None of these methods has been adopted for practical study of the sensibility in the hand. The reasons are several. The dye tests, especially, cause the patient considerable discomfort, and before the test the skin must be treated with a substance which may affect the sweating to be examined. These methods do not draw a distinct borderline between regions with different sweating reactions, which is essential for the small areas involved in the hand.

Hitherto, and this is an important point, it has been thought that the neurological methods were able to give a differentiated picture of the sensibility in the hand, and that testing of the sudomotor function could only give a simple "yes" or "no." For this reason tests based on the sudomotor function have been considered inferior for determining sensory function. No attempt at all seems to have been made to determine what qualities of sensibility might correspond to the sudomotor function. My aforementioned study, however, showed that whenever an area of the hand showed normal sudomotor function it also possessed normal tactile gnosis. This opened up a new perspective, and I began a search for a method of registering changes in sudomotor function that was more sensitive and exact than the previous ones, but at the same time simple to perform. Two paths led to two different methods. These methods I have called the ninhydrin and iodine-starch printing tests.

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PRINTING TESTS

Anatomical background—The secretion of sweat is regulated by the sympathetic nervous system. The fibres of this system enter the brachial plexus in the cervical region far proximally in the form of post-ganglionic fibres (Fig. 5), and then follow the sensory pathways to the periphery. When a peripheral nerve is injured the sweat glands in the skin of the region supplied by this nerve lose their innervation. Only the proximal parts of the brachial plexus, proximal to the level at which the sympathetic fibres enter, can be injured without damaging the corresponding sudomotor function in the peripheral region. All the techniques and conclusions now to be described, therefore, apply to injuries to the peripheral sensory nerves distal to this point in the arm. The methods are of no help when the most proximal part of the plexus or the central nervous system is injured.

This exception is of no great importance from a practical point of view, for the great majority of the injuries in question affect the peripheral nerves at a more distal level.

Principles and technique—With both the ninhydrin and odine-starch printing methods, the orifices of the functioning sweat glands are shown in prints of the pulps of the fingers on a strip of paper. The site of a nerve lesion is usually known or is indicated by the presence of a tender neuroma or a scar in the skin. Consequently, the cutaneous sensibility of the skin between the pulp and the nerve lesion can be judged from the prints (Fig. 6).

Ninhydrin method—Hier, Cornbleet and Bergeim (1946) found ten different amino acids in sweat. They calculated that the average cubic centimetre of sweat contained 0.44 milligrams of amino acids. Because of the way they collected their material, however, some of it may have come from the epithelium rather than directly from the glands. Pankow (1953) found the following amino acids in human sweat: asparaginic acid, glutaminic acid, serine, thionin, alanine, valine and methionine. Král and Zenisek (1955) demonstrated that the amino acids excreted in sweat increased with heavy labour.

Ninhydrin 'stains' amino acids and lower peptides with great sensitivity. Odén recognised the value of this for criminological purposes. He and Hofsten (1954) discovered that a moist finger pressed against paper left a print which could be dyed with a ninhydrin solution many years later. They sprayed the paper with a 0.2 per cent dilution in acetone, acidified by glacial acetic acid, dried it in air and then warmed it for a few minutes at about 120 degrees centigrade. They then fixed the print by treating the paper with a solution of copper nitrate.

Odén and Hofsten worked out their method for bringing out old fingerprints for identification. I found that the same principle could be used for testing sensibility in the hand.
What is wanted for testing sensibility is not a complete fingerprint, but a punctiform representation of the glandular orifices of the finger pulps. The ninhydrin printing test I worked out aims to show as many of the functioning glands as possible in printed dots. The same is true of the iodine-starch printing method.

Water proved to bring out substances stainable with ninhydrin from the surface of the skin, even when the sudomotor function was completely absent; so the paper must not be moist, and there must not be any extraneous moisture on the hands. It is necessary, of course, to use paper which does not contain substances stainable with ninhydrin in the glue or elsewhere. The method is so sensitive that the examiner must be careful not to touch the strips with his hands, or else unwanted prints will appear after a few days, even if the paper is not heated. **Iodine-starch printing method**—Randall (1953) modified Minor’s test by having the starch incorporated in a paper and pressing the skin against this paper. Dole and Thaysen (1953) improved the method by having both the starch and iodine put into the paper. When the skin was pressed against this paper the water in the sweat caused blue spots on the paper, the size of which corresponded to the amount of water given off by the skin. They claimed that they could get a print from every functioning gland with their method. They did not use it for studying sensibility, but with minor modification it proved to be valuable for my studies.

**Details in the performance of the tests**—It must be emphasised that exact and clean work and training are always necessary to get reliable prints. The prints are obtained by pressing the pulps of the fingers, one at a time, steadily against a strip of paper measuring about fifteen centimetres by three. The outline of the finger tip is traced with pencil (containing no dye) on the paper. Sometimes it is useful to roll the tip of the fingers slowly and steadily from side to side so as to get its lateral surfaces on the print, especially in the case of the thumb where the border zones innervated by the radial nerve are of great practical importance.

The secretion of sweat in the pulps must not be too intense. Impressions like that shown in Figure 7 are the ones desired. Skin too moist leaves blurred impressions, as in Figure 8, and makes it difficult or impossible to draw an exact line between areas of normal and reduced sensibility. The secretion from strongly sweating regions is apt to contaminate the dry areas. In such a case the skin should be washed with soap and water, ether or alcohol, and then well dried.

The secretion must not be too weak, otherwise there will be too few dots, or none at all. When the patient is cold or has been given medication, or during anaesthesia, he may perspire so little that not even a normal area leaves a print. Then the secretion must be stimulated. Salicylic acid, warm tea and exercise are helpful. Pilocarpine has been found to be of no value. For special studies intense stimulation can be induced by a subcutaneous local injection of mecholyl (beta-acetyl-methyl-choline-hydrochloric acid).

As a rule, however, good prints are obtained in the ordinary room temperature in Sweden (about 18 degrees centigrade—64-4 degrees Fahrenheit) without previous preparation of the patient.

If there is a contracture or some other deformity in the finger, it may be difficult to take the print in the way just described. Then a piece of paper the size of a postage stamp can be pressed against the finger pulp, either with a piece of rubber sponge, or in a special metal...
holder (Fig. 9) to which an elastic band has been attached so as to give a cushioned printing surface. It takes practice to get good prints in cases of this kind.

Prints can also be obtained from parts of the hand other than the pulps of the fingers, but as a rule nothing is gained from taking a print of the whole hand.

For the ninhydrin printing test several ordinary kinds of white writing paper proved useful. The paper recommended later for the iodine-starch method stained in a disturbing way. Porous paper is not good. The best way to develop the prints is to dip them in a 1 per cent ninhydrin solution in acetone, which will keep for several months. About ten millilitres are mixed with a few drops of glacial acetic acid in a cuvette. The acidulated solution will only keep for one or two weeks. The paper strips dry quickly, and after drying they are warmed in air at 100–120 degrees centigrade for five or ten minutes. Thereupon the dots become visible, but it is advisable to wait a few days before fixing the prints, because they often grow more distinct. They are fixed by dipping them in the solution described by Odén—a 1 per cent solution of copper nitrate in a 5 : 95 mixture of water and methyl alcohol or acetone, acidified by a few drops of concentrated nitric acid per hundred millilitres.

For the iodine-starch printing test, it is important to get suitable paper. Dole and Thaysen (1953) used "80 lb. substance, white richfold coated (Rex Stationery Co., New York City)," and it is the only type with which I have been able to get good results. The strips are put over a filter paper uppermost in a petri dish on the bottom of which are placed a number of iodine crystals. The dish is covered with a lid and heated at about 60 degrees centigrade for a few minutes. The iodine becomes sublimated and stains the strips yellow. It makes no difference if the staining is slightly uneven. The paper quickly loses the iodine; so the strips should be used soon after they are prepared. Distinct prints can be obtained, which are easy to study when they are moderately enlarged.

Comparison between iodine-starch and ninhydrin printing methods—The iodine-starch method has the advantage that the print can be seen immediately, without having to be developed. Sometimes, also, it gives more distinct dots and so it is perhaps better when the print is to be studied under the microscope for special purposes. The print remains legible for several weeks at least. If it is needed for longer it must be photographed. A photostat copy is sometimes sufficient, but some detail is lost. Nevertheless, the iodine-starch prints photograph better than the ninhydrin prints.

The great advantage of the ninhydrin method lies in the fact that the print can be fixed and preserved. This makes it possible to compare prints taken at different times in their original form. This is valuable both for scientific work and for clinical purposes. For this reason I have used the ninhydrin method more often in this study. Otherwise, in my experience, the methods are of about equal value, and therefore they will be considered together henceforth.

As mentioned, the epidermis of the skin also contains substances that stain with ninhydrin. Consequently, when moist paper is used, intense prints are obtained even from a surface which has lost all power of secretion. These stainable substances probably result from the disintegration of proteins in the surface of the skin. From a theoretical point of view, it would be interesting to know whether the results of the ninhydrin method are dependent

![Fig. 9](image-url)
mainly on the excreted amino acids, and not on the secretion of water as are those of the
iodine-starch method. In such a case the methods would differ in principle.

I made some attempts to wash out the amino acids from the skin to see if this were so.
A normal subject was made to perspire freely with salicylic acid and warm tea. When one of
his finger pulps was washed with soap and water for twenty-five periods of two to ten minutes
and tested between times, the ninhydrin prints became much weaker but they never disappeared.
With every washing they took on more the character of punctiform prints of the sweat
 gland orifices. Washing with ether, alcohol and acetone had the same effect. This is a strong
indication that the stainable substances were directly excreted from the glands. It does not
seem likely, even though their corkscrew paths through the horny layer are long, that the
 epidermis could continually give off new amounts of stainable substances from the walls of
the paths to the water in the sweat. The probability is, therefore, that the ninhydrin test
registers the excreted amino acids, while the iodine-starch test registers the water excreted.
So far, this has not meant any practical difference between the two methods.

RELATIONSHIP BETWEEN SENSIBILITY AND SUDOMOTOR FUNCTION

Recent nerve injury with total loss of sensibility in corresponding region—When a peripheral
nerve is severed, the area of skin that it supplies stops sweating almost at once and has
certainly done so by the time the patient reaches a doctor. On examination it is then seen
that the regions with intact sensory function sweat normally (perhaps a little more than
usual) and give normal prints, but the denervated regions leave no print at all. Figure 10
gives a clear illustration of this. It shows the case of a hand with the median nerve severed,
resulting in loss of sensibility on the volar surface of the thumb, index finger, middle finger
and partly on the ring finger. Another case is seen in Figure 11. There the thumb and little
finger show normal sensibility while the ring finger has lost its sensibility because of the injury
at the base of the finger. The prints show this clearly. There is no doubt about the relationship
in these cases.

Experiments with nerve block—In order to study how the loss and return of the sensibility
were related to the sudomotor function, the nerve was put out of function temporarily in a
number of cases. The median nerve was blocked at the wrist in nine cases, and the ulnar
nerve at the elbow in seven. The brachial plexus was anaesthetised in ten cases. The subjects
were of both sexes and varied in age from sixteen upwards. None of them had any nerve injury.

In some cases the experiments were done in connection with an operation, in other cases
not. They were continued until full sensibility had returned. The nerve block was produced
with xylocaine in a 2 per cent solution to which epinephrine was added in the proportion of
1:80,000. A comparison was made between the sudomotor function, registered in the manner
previously described, and the results of the customary tests of cutaneous sensibility.

The results being essentially the same in all the cases, I shall only give an example of
each kind.

Blocking of median nerve—The prints are seen in Figures 12 to 15. The subject was a man of
thirty-five years of age with a normal right arm. No premedication was used. The room
temperature was 20 degrees centigrade. No operation was done. The prints of the finger
pulps were normal (Fig. 12). The median nerve was blocked at wrist level with xylocaine.

Thirty minutes after the injection there was total anaesthesia and analgesia in the median
nerve area. Thumb opposition was lost. The iodine-starch and ninhydrin tests (Fig. 13)
showed that the area supplied by the median nerve had stopped sweating entirely, but that
the area supplied by the ulnar nerve perspired normally, as well as the area on the lateral
surfaces of the thumb innervated as border zones by the radial nerve. Repeated testing gave
the same result until four hours after the injection, when thumb opposition began to return.
Five and a half hours after the injection pinpricks and touch began to be perceived in the anaesthetised region. Return of the sudomotor function was also manifested in the form of twelve dots in the print from the pulp of the thumb, one from the index finger and eight from the middle finger (Fig. 14).

Fig. 10
Ninhydrin printing test. Median nerve severed at wrist level. Pulp of the thumb rolled from side to side over paper to include lateral surfaces in the examination. Dorso-lateral borders of thumb distally innervated by radial nerve. The normal hand is shown above for comparison.

Fig. 11
Ninhydrin printing test. Thumb and little finger show normal sensibility. Index and middle fingers lost. Ring finger has no tactile gnosis, because of an injury at the base of the finger, where both digital nerves were severed.

Six and a half hours after the injection all that was left of the anaesthesia was a slightly numb feeling in the index finger. The sensibility was normal except that the two-point discrimination was about two or three millimetres worse in the index finger than in the little finger. The sudomotor tests gave normal results (Fig. 15).
Blocking of ulnar nerve—The same arm as in the previous experiment was used four days later (Figs. 16 to 19). The same experimental conditions prevailed. The initial fingerprints were normal (Fig. 16). The effect on the motor function will be disregarded here. The ulnar nerve was blocked with xylocaine.

Twenty-five minutes after the injection the involved region was completely insensible (Fig. 17). Repeated testing showed no change until three and a half hours after the injection,

![Fig. 12](image1)

![Fig. 13](image2)

![Fig. 14](image3)

![Fig. 15](image4)

Median nerve blocked at wrist level with xylocaine. Figure 12—Normal prints before injection. Figure 13—Thirty minutes after injection. Loss of tactile gnosis in median nerve area. Thumb rolled over paper to show remaining sensibility in border zones supplied by radial nerve. Figure 14—Three and a half hours after injection. Function has begun to return. Figure 15—Six and a half hours after injection. Full function restored.

when the sensibility began to return. The analgesia was then no longer sufficient for an operation. The sudomotor function began to return but the dots were still much fewer than in the median nerve region (Fig. 18). From then on both the sensibility and sudomotor function returned rapidly.

Four hours and twenty minutes after the injection all that remained was slight numbness in the ulnar nerve region. Points seven to eight millimetres apart were distinguished in the
pulp of the little finger as against four millimetres apart in the middle finger, but no other difference could be found. By this time the sudomotor function was almost normal again (Fig. 19).

*Brachial plexus anaesthesia*—This form of anaesthesia was used for ten similar experiments. In these cases a minor operation was done in the hand in a bloodless field produced by a pneumatic tourniquet on the upper arm. This did not appear to affect the results in any way.

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**Fig. 16**

*Ulnar nerve blocked at elbow. Figure 16—Normal prints before injection.*

**Fig. 17**

*Figure 17—Twenty-five minutes after injection. Tactile gnosis has disappeared in ulnar nerve area.*

**Fig. 18**

*Figure 18—Three and a half hours after injection. Function has begun to return.*

**Fig. 19**

*Figure 19—Four hours and twenty minutes after injection. Almost normal function restored.*

The results were essentially the same as when the median and the ulnar nerve were blocked. In some cases the sensibility returned first to the area supplied by the median nerve and in others to the area supplied by the ulnar nerve. The first signs of restoration of sensibility always coincided with the first signs of restoration of the sweat gland function. It took about an hour from these first signs until the function was almost completely restored.

These experiments show clearly how the sensibility and sudomotor function are interrelated. As soon as the first dots appeared in the prints, some capacity to perceive pain

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TABLE I

COMPARISON BETWEEN GRIP FUNCTION, TWO-POINT DISCRIMINATION AND SUDOMOTOR FUNCTION

<table>
<thead>
<tr>
<th>Case number</th>
<th>Age at injury (years)</th>
<th>Age at examination (years)</th>
<th>Interval between injury and nerve repair (months)</th>
<th>Interval between nerve repair and follow-up examination (months)</th>
<th>Protective sensibility</th>
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<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>41</td>
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<td>51</td>
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<td>+</td>
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<td>4</td>
<td>0 (before repair)</td>
<td>+</td>
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<td>6</td>
<td>55</td>
<td>57</td>
<td>8</td>
<td>19</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>18</td>
<td>18</td>
<td>6</td>
<td>0 (before repair)</td>
<td>Thumb + Index - Middle -</td>
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<tr>
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<td>-</td>
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<tr>
<td>10</td>
<td>28</td>
<td>66</td>
<td>No repair</td>
<td>38 (after injury)</td>
<td>+</td>
</tr>
</tbody>
</table>

Comments: In Case 7 all sensory branches in the palm were severed; in the others the median nerve was divided at wrist level or in the middle of the

returned. When the sudomotor function was almost restored, the two-point discrimination began to approach the normal. Only a slight subjective feeling of numbness, hardly possible to register objectively, then remained for a few hours, the length of time varying from case to case.

Accordingly, these methods of registering the sweat-gland function provide an exact and objective means of following the variations in the sensibility of the hand produced by nerve block in the arm.

This is probably the only method by which the effect and duration of a local anaesthetic agent can be measured objectively.

COMPARISON BETWEEN TACTILE GNOsis AND SUDOMotor FUNCTION AFTER LONG-STANDING MEDIAN NERVE INJURIES

In my aforementioned investigation I compared the results of the customary methods of examining sensibility with the actual functional usefulness of the same sensibility in ten cases. Here I shall compare the results of the objective printing methods in the same ten cases with the results of the two-point discrimination test, the only one of the subjective methods useful for judging the functional value of hand sensibility and for which the results can be given in figures. The results of this are seen in Table I and Figure 20. Normal sudomotor function is indicated by 3, moderately reduced by 2, greatly reduced by 1, and absent by 0.

It is clear that the better the tactile gnosia the denser are the dots from the orifices of the sweat glands in the prints. The presence of a few dots in a print does not mean that the area possesses useful sensibility. When about half the normal number of sweat glands leave an imprint, some tactile gnosia is present, and as the number of dots increases so does the tactile gnosia of the area. This makes it possible, for example, to examine the return of tactile gnosia
after nerve suture, which is not possible with Guttmann's quinizarin method. As seen from the table, the two-point discrimination test and printing tests agree about the condition of the grip sensibility. A person with normal sudomotor function can perform the picking-up test, though perhaps not with normal speed, and distinguish two points down to twelve or fifteen millimetres apart. When the sudomotor function is absent, on the other hand, two-point discrimination is always impaired and the precision-sensory grip is lost. There is some evidence that the sudomotor function returns a few months before the tactile gnosis, but this is not yet established.

An apparent exception is sometimes found in the thumb. Thus in Case 8 the thumb possessed a fair sudomotor function (grade 2) but poor two-point discrimination. Case 6 showed similar conditions. These exceptions are only apparent, however. When the dorsal nerves of the thumb are blocked dorsally at the base of the distal phalanx with xylocaine the sudomotor function disappears at once. Closer study shows that in these cases it is mainly the lateral narrow border zones volarly on the distal phalanx of the thumb which leave prints of the sudomotor function. However, these narrow borders are so small that it is difficult or impossible to examine the tactile gnosis there with Weber's compasses, and so this method is apt to be misleading. The coin test often gives a clear verdict about the tactile gnosis in these small border zones (Fig. 10). Figure 20 shows a few examples of how the prints look after blocking the dorsal nerves to these zones. Then the results agree entirely with those of two-point discrimination.

Accordingly, Weber's compass test is apt to be unreliable in detailed examinations of narrow areas, especially when the testing can only be made along one line and cannot be checked by putting the legs of the compass at right angles to their first position. However, the prints give reliable results in these cases. This is important, because in a case of median nerve injury at wrist level the border zones are often what provide the thumb with good
Prints from Cases 1-10, Table I. The three extra prints at the right in Cases 2, 7 and 8 were made after blocking the radial nerve branches to the thumb. The prints are difficult to reproduce photographically without losing some of the details because the fixing solution shades the paper strips pale green.
tactile gnosis and make it useful for gripping with the ring and little fingers. When the border zones are insensitive the functional value of the thumb is greatly reduced. If the zones are broad the thumb may remain almost as useful as it was before it was injured.

DISCUSSION

It has been said (Guttmann 1940, Zachary and Roaf 1954) that loss of the sudomotor function is generally, but not always, accompanied by loss of sensibility. They found most exceptions in the trunk and face. These authors made little mention of different kinds of sensibility. In my experience, the loss of tactile gnosis in the hand is invariably accompanied by the loss of sudomotor function and vice versa, and the borderline between normal and abnormal areas can always be determined as exactly as it is possible to do with any known testing method.

It is of no use, when judging hand function, to divide the regions of nerve distribution in the ordinary way into autonomous and intermediary or to test separate physiological modalities. The so-called compensatory activity of nerve fibres from neighbouring, normally innervated zones occurring early after denervation does not provide tactile gnosis. For this there must be real nerve regeneration through the main trunk of the region. In none of the aforementioned cases without real nerve regeneration did the area lacking tactile gnosis distinctly decrease from what would correspond to the region normally innervated by the injured nerve. An illustrative case is Case 10, in which tactile gnosis was completely lacking in the whole median nerve area thirty-eight years after the denervation. It makes no difference even when a skin region is doubly innervated, as in the case of the tip of the thumb. After loss of one of the sources of innervation in these areas, what remains of the tactile gnosis undergoes no change unless repair is done.

Thus, in the hand, the regions which possess sensibility of the kind providing tactile gnosis coincide with the ones which have complete or almost complete sudomotor function. So far as is known, this parallelism is based on a purely anatomical coincidence, namely, that these two nerve elements follow the same pathway.

Comparison between the best of the subjective methods—the test of two-point discrimination—and the printing methods shows the following.

1. When the subjective factors are reduced to a minimum—for example, with a skilful examiner and the same co-operative experimental subject—differences can be demonstrated with the two-point discrimination test that are beyond the power of the printing methods in their present form. This is true, for example, of the differences normally present between the pulps of the index and little fingers, between the pulp of the finger and the volar area of the basal phalanx, and between the latter area and the palm. In all these instances, the two areas differ by a few millimetres in their ability to distinguish between two contacts.

2. Only the printing methods can reliably demonstrate small degrees of residual function in a greatly damaged nerve trunk. Only they, likewise, can be relied upon for testing narrow areas.

3. The boundaries between regions with and without tactile gnosis can be drawn more precisely with the printing methods, especially when tactile discrimination falls to ten millimetres of separation or more.

4. When the tactile gnosis is reduced in a region that may be supplied by two nerves, their relative share in the function can be demonstrated with nerve block and prints much more exactly than by any subjective method. This is sometimes useful to know when an operation is planned.

5. The greatest advantages of the printing methods are that they are completely objective and that the original test results can be kept.
To sum up: the tactile gnosis in the hand can be demonstrated by examining the sudomotor function in the same region with the ninhydrin and iodine-starch printing methods. When the sudomotor function is defective, a corresponding defect in tactile gnosis is present.

FIG. 21
Some sudomotor function returned to a skin graft in fourteen months, but tactile gnosis did not return.

Man aged thirty-five. Electrical burn. Two and a half months later, scar excision. Graft from thigh; thickness about three-quarters of the corium. No important nerve injury. Fourteen months later the sensibility around the graft was normal. Thus touch was perceived with the estesiometer on 0·5 gramme pressure and the two-point discrimination was normal. The graft contained a narrow zone (a) where 1·5 grammes were perceived, but otherwise it showed little sensibility. Heavy touch was perceived and likewise the estesiometer on 2·5 grammes pressure. Two-point discrimination was lacking. Distinct sweat gland function, however, had returned in the proximal part of the graft, as was shown by coarse clumsy prints (b) (indicated by interrupted lines). The function disappeared on plexus anaesthesia, as did the sweat gland function in the normal skin beside the graft, but it returned to both places when the anaesthesia disappeared.

The exceptions to this rule are few and quite distinct, and cause no great trouble. It has already been mentioned that the parallel ceases when the plexus is injured proximal to the site of entry of the sympathetic post-ganglionic fibres in the plexus. Likewise, operations on, or injuries to, the sympathetic nervous system in the cervical region may distort the results.
In addition to these obvious exceptions, however, there is one other which is of great interest both from a practical and theoretical point of view.

**Exception to rule**—The sudomotor function comes back to skin transplants but not the tactile gnosis. Many believe that sensibility comes back to all transplants after one or two years, both to so-called intermediary grafts and whole-skin grafts and flaps possessing subcutaneous fat. That they regain sweat gland function has been shown by Löfgren (1951) and others. The return of sensibility to skin grafts has been studied by Napier (1952) and others. Napier observed that three different types of reinnervation took place, and made a careful analysis of the anatomical factors that determined the forms in which the sensibility returned. He did not study the returning sensibility by means of two-point discrimination, though he used this

**FIG. 22**

Sudomotor function, but not tactile gnosis, returned to an abdominal flap in seventeen months.

The same patient as in Figure 21, also had a deep burn on the front of the wrist and palm of his other hand. Many centimetres were lost of both the median and ulnar nerves and of several flexor tendons. After excision of a deep scar and operations on the nerves and tendons the defect was covered with an abdominal flap (a). This flap was released from the abdomen seventeen months before examination. The final size of the flap was 11 × 12 centimetres. At examination the two-point discrimination was 10–12 millimetres in the skin proximal to the flap, and the sensibility there was normal in every respect. Two-point discrimination was lacking in the flap. Distally to this it was present (about 20 millimetres) in a narrow zone and, distally to this, lacking again. Estesiomter values are shown in the figure. The algesiometer needle caused pain of atypical character on 1 gramme pressure in the small zone distal to the flap. Distal to this no pain was perceived with loads up to 10 grammes, and the same was true of the whole flap. Sweat gland function proximal to the flap was also normal. Distal to the flap it was lacking. The flap itself had distinctly functioning sweat glands, though they gave coarse and clumsy prints (b) compared with normal skin and with the abdominal area from which the flap was taken. The function disappeared during plexus anaesthesia but returned with the normal sweat secretion of the skin proximal to the flap when the effect of the nerve block disappeared. Only a small area distally in the flap, where no sensibility at all was observed, gave no prints. Distal to the flap where the skin was left in situ there were still no signs of sweat gland function.
method elsewhere in the same work. It is easy to deduce why: two-point discrimination does not return in the skin graft, at least to any useful degree.

I compared the sensibility with the sudomotor function with all the usual methods and with the printing methods in seven skin transplants which had been in place for a long time. Essentially the same results were obtained in all of them—namely, returning sudomotor function but no tactile gnosis (Figs. 21 to 23). A number of grafts that had been in place for only three or four months were also tested and proved to lack the sweat gland function and all sensibility. Moreover, several other whole skin grafts and flaps which had been in place for up to nine years were tested only for sudomotor function and two-point discrimination. All proved to lack the degree of discrimination necessary for tactile gnosia, though they possessed the sweat gland function. Among these were grafts that were transferred from one part of the hand to another, as cross-finger flaps, and thus consisted of skin which before the transfer had good tactile gnosia.

These observations show that skin grafts transferred to the hand do not regain tactile gnosia. Thus in every case in which the graft was so situated that its usefulness for a precision-sensory grip could be tested, the power of tactile gnosia was lacking and the picking-up test was a failure,

It is interesting, however, that the sudomotor function returned. In skin grafts, accordingly, it does not vary parallelly with the tactile gnosia. It may even return to tissue in which protective sensibility is still lacking, as in the case shown in Figure 23.

The sweat glands, however, did not function in the normal way. The prints were not those of the delicate glandular openings in normal skin, even on the abdomen. Instead, they consisted of blurred and irregular spots, as if a large amount of sweat had collected in a dilated channel and gushed out all at once.

A fact of great theoretical interest is that skin which is denervated by nerve injury but still normally connected with the surrounding tissue does not acquire the same sudomotor function as transplanted skin. Both may acquire about the same capacity to register touch and pain. Both lose the power to distinguish between two separate points of contact, but this capacity can only come back to skin in situ and only after successful nerve repair. The sweating function which returns to the transplant is controlled by the nerves for, in my cases, it disappeared when the brachial plexus was blocked.

![Fig. 23](image)

Some sudomotor function, but not tactile gnosia, returned to a flap in ten months. Ninhydrin printing test. Man aged thirty-nine. Avulsion injury with loss of the skin from dorsum of hand. The area was covered with an abdominal flap 9 × 10 centimetres in size. The flap was detached ten months before the examination. The flap (a) showed practically no form of sensibility. Only rough handling like lifting a fold of tissue with a pair of forceps was perceived. There was no protective sensibility. Proximal to the flap and on both sides the sensibility was normal. Distal to the flap, however, was a denervated region about 3 centimetres wide, which showed no two-point discrimination and did not react to 10 grammes load on the algesiometer needle or 2.5 grammes pressure with the estesiometer. Proximal to the flap the sweat gland function was normal. Distal to it, in the anaesthetic zone, it was lacking. The flap itself showed distinct sweating in the form of clumsy spots in the prints. This secretion, too, disappeared when the brachial plexus was blocked.
OBJECTIVE METHODS FOR DETERMINING THE FUNCTIONAL VALUE OF SENSIBILITY IN THE HAND

An explanation for this might be that new nerve fibres to the denervated sweat glands follow along with the new vessels which grow into the graft. Denervated skin in situ which does not acquire new vessels would not have the same chance to have its sweat glands reinnervated.

To summarise: tactile gnosis does not return to skin grafts but the sudomotor function usually returns after a year or so. Apart from what has been said before, this is the only exception to the rule that in the hand the tactile gnosis varies with the sudomotor function. The exception is so clear cut that it should not cause any difficulty.

PROCEDURE FOR DETERMINING THE FUNCTIONAL VALUE OF THE CUTANEOUS SENSIBILITY IN A HAND

A hand or part of a hand that lacks tactile gnosis, even if it possesses one or more of the aforementioned modalities of sensibility, is nevertheless "blind"—that is, it cannot be used without the aid of the eye; it does not know whether or how it holds an object, or what the object is. Only by determining the tactile gnosis can a real idea be obtained of the value of the cutaneous sensibility for the precision-sensory grip.

The functional value of the cutaneous sensibility in a hand, therefore, should be determined in the following way.

Tactile gnosis for precision-sensory grip (Fig. 3)—This can be determined objectively with the ninhydrin or iodine-starch printing methods. Subjective methods that may be used as a complement are the two-point discrimination test, Seddon's coin test and the picking-up test.

Sensibility necessary for gross grip (Fig. 4)—The presence of this function can be determined objectively by looking for callosities and similar signs of usage in the hand, and subjectively by testing the hand in use.

Protective sensibility—This must be judged from the history unless typical lesions show that it is absent.

The methods routine for examining the sensibility to touch and pain in a hand must be reserved for the neurological purposes mentioned, where they are of proved value.

EXAMPLES OF THE PRACTICAL APPLICATION OF THE METHODS

1. Guttman has already shown with the quinizarin test that the regions supplied by the various nerves vary from hand to hand. The methods described here are much more exact, simpler to perform and are not objectionable for the patient. They permit detailed study of the nerve distribution.

2. Their value for study of local anaesthetics has already been discussed.

3. Hitherto there has been no objective method for judging disability in the sensibility in the hand. The customary methods, all subjective, are highly unsatisfactory and result in unfair financial consequences. The simple methods described here give the information desired. It is easy to keep records of the prints.

4. When there is an acute injury involving essential nerves in the hand, particularly the median and ulnar nerves, mistakes are often made when the hand is first treated. Because of the injured person's mental state after the injury, it is easy to understand that serious mistakes are made with subjective methods, mistakes that have a grave effect on the future earning capacity of the patient. Errors of this kind can be avoided by using the objective diagnostic methods (naturally before any nerve block for anaesthesia).

5. In difficult elective cases important diagnostic details can be clarified before operation much more exactly than with the other more time-consuming methods. The following cases illustrate this.
Case 1—A woman aged sixty-one suffered from nerve compression in the carpal tunnel caused by chronic non-specific tenosynovitis. For about six months she had noticed a swelling at the front of both wrists, much greater on the right side. Her fingers sometimes felt numb and clumsy—for instance, when she raised a cup to her mouth, buttoned her clothes or knitted. The only objective signs were a swelling over the front of the carpus, weakness and slight atrophy of the thenar muscles, and tactile discrimination of about six millimetres in the pulp of the right index finger as compared with three to four millimetres in the index finger of the other hand and in the ulnar-innervated fingers. The ninhydrin method, combined with dorsal block of the radial branches, showed that the sudomotor function in the median nerve region had deteriorated as compared to the normal hand. Operation disclosed typical chronic non-specific tenosynovitis compressing the nerve in the carpal tunnel.

In this case, since it was possible to verify the change in sensibility objectively, the hand was operated upon early, while the nerve lesion was still reversible.

Case 2—A girl of eighteen had cut the palm of her right hand with glass six months before she came to us. It was then seen that the thenar muscles were still innervated. This did not necessarily mean, however, that the motor function of the median nerve remained, but may have been due to an innervation of most of the muscles by the ulnar nerve. The sensibility was reduced but not absent in the pulp of the thumb. The same was true of the ring and little fingers. It was lost entirely in the volar surface of the index and middle fingers. It was known that the injury must lie near the branching area of the median nerve in the palm, which meant a difficult dissection in scar tissue. As the sensibility was already so much reduced in this hand, it was important not to injure any branch where there was still some useful nerve continuity or where regeneration had started. Yet waiting meant taking the risk that nerve suture would have to be done at a later, much more unfavourable, date.

Good prints were obtained with the ninhydrin method, showing tactile gnosia in the pulp of the thumb and a small amount in the ring and little fingers. It was also found that the dorsal skin of the ring and little fingers had retained its capacity to perspire even beyond the middle phalanges. This was surprising, for the region supplied by the dorsal nerves usually ends at the proximal interphalangeal joints. There was a possibility that it meant that the volar nerves still functioned to some extent. However, on dorsal block of the nerve branches on the thumb, little finger and ring finger, the perspiration stopped entirely, both volarily and dorsally. This established that all the volar nerve branches must have been cut off and that the volar sensibility in both the thumb and in the ring and little fingers must have been derived from the dorsal branches of the radial and ulnar nerves respectively. No subjective methods would have been able to establish with such certainty that this unusual anatomical anomaly was present. Operation completely verified the pre-operative diagnosis.

6. The methods may provide the only means of making a correct prognosis at an early stage of nerve injury, as the following case shows.

Case 3—A man aged thirty-seven had sustained a crushing injury of the upper arm, with a transverse wound ten centimetres above the elbow on the inner aspect of the arm. There were all the signs of severe injury to the median nerve with loss, perhaps total, of motor function and sensibility, and also an incomplete lesion of the ulnar nerve. Immediate testing with the ninhydrin method (Figs. 24 and 25) showed about fifteen sweat gland openings in the pulp of the index finger, reduction of the sudomotor function in the middle finger and great reduction of this function in the thumb. The perspiration in the thumb and middle finger might have been explained by anomalous innervation. However, it was hardly possible so to explain the function in the index finger: it must have meant that there was nerve conduction past the site of the lesion. Because of this, the outlook was pronounced favourable. A week later the print shown in Figure 25 was obtained. With subjective methods it was hardly possible to demonstrate any sensibility coming from the median nerve in the thumb and index finger, and the motor function was still almost completely lacking.

Six months later the prints were almost normal. The sensibility was then normal in the middle finger. Points ten to twenty millimetres apart could be distinguished in the pulp of the index finger and twelve to fourteen millimetres apart in the pulp of the thumb. There was already considerable motor regeneration and it was still in progress.

Thus, it was possible with this method to exclude complete interruption of the nerve on the day of the accident. With other methods this could not have been done until months later.

Theoretically it should be possible to use the printing methods for distinguishing between pre-ganglionic and post-ganglionic injuries of the plexus. In such a case they could be used instead of the much more complicated "cold dilation test" (Bonney 1954) used for this purpose. This would make it easier to foretell the outcome of a severe plexus injury at an
Case 3—Crushing injury above elbow with open wound. No unquestionable median nerve function could be demonstrated with the customary methods. However, the ninhydrin printing test revealed nerve function even in the index finger, and as this could hardly have been due to an anatomical variation, the prognosis was pronounced favourable at the first examination (Fig. 24). A week later the test showed improvement (Fig. 25), and a few months later good, but not normal, function was restored.

early stage and eliminate the long period of expectancy before starting on reconstruction.
I have not had access to any cases suitable for study of this kind.
7. These methods can be used in many ways for planning reconstruction of the grip. A number of these possibilities will be demonstrated in another paper.

SUMMARY
1. It was observed clinically that tactile gnosis varies directly with the sudomotor function in the hand.
2. Two methods of fingerprinting were elaborated to register the sudomotor function, and consequently the tactile gnosis objectively. They are sensitive, simple to perform and suitable for clinical work. Their anatomical background, sources of error and relative value are discussed.
3. The correspondence between the sudomotor function, determined with these methods, and the tactile gnosis was established. This was done by, firstly, comparing the regions which did not perspire with the ones which became insensible on total denervation of a region of the hand; secondly, by examining the loss of function after nerve block; and thirdly, by comparing the tactile gnosis and sudomotor function in cases of residual median nerve defect.
4. These two qualities do not accompany each other in skin grafts. Grafts regain sudomotor function but never tactile gnosis.
5. A practical procedure for determining the functional value of the cutaneous sensibility in the hand is described.
6. Cases are related illustrating the usefulness of objective study of the sensibility in the hand.
REFERENCES


