CLINICAL APPLICATIONS IN MYOELECTRIC CONTROL[a]

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SELECTION OF CONTROL SITES FOR MYOELECTRIC SWITCHES

Background Information

Although research in myoelectric control appeared as a new field less than 10 years ago (1), fundamental studies underlying the recent developments were under way in the early 1950's. Inman (2) and his associates, for example, investigated the relationships between muscle tension and differences in surface electrical potential. They concluded that integrated electrical activity as demonstrated by electromyography does parallel tension in human muscle contracting isometrically. With respect to muscle length, their view was that no quantitative relationship existed between the electromyogram and tension when the muscle length was allowed to change. Later, however, Bigland and Lippold (3) showed that when shortening or lengthening took place at a constant velocity, electrical activity remained directly proportional to tension. The problem of using these myoelectric currents in the control of externally powered devices was under investigation at about the same time, notably by Battye and his associates (4).

With the sudden acceleration in technologic developments after 1960, interest in this field became centered largely on the design of suitable mechanical devices and electrodes. In 1966 Scott (5) reviewed the myoelectric systems then being tested around the world. One such control system, developed for below-elbow prostheses, incorporates control sites over forearm stump muscles which activate prehension of an artificial hand. Another system makes use of control sites over the trapezius muscle to activate an artificial hand or to initiate electrical stimulation

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of the extensor digitorum communis muscle to provide finger extension. The mode of control has also been considered; for example, a control site may provide on-off control of two functions—a slight contraction of the muscle activating one function such as finger extension, and a stronger contraction activating finger flexion. A greater number of functions might be controlled by varying the combinations of muscles. If the concept of voluntary control of single motor units within a muscle can be expanded, then perhaps a coding system can be developed whereby each control function is represented by a distinct number of control motor units (6). Already accomplished is the implementation of proportional control, which enables the velocity and force of prehension to be controlled by the amount of contraction of the control muscle.

Objectives

The objective of this study is to provide measurements on which to base the choice of a control site for a myoelectric switch. By amplifying the potential differences produced at the control site, the myoelectric switch activates an orthotic or prosthetic device. This system is especially suitable for patients with severe quadriplegia who are unable to use manually operated devices but require something to facilitate prehension and hand positioning. A good control site must be an area where the patient can voluntarily generate sufficiently high potential differences by a simple muscle contraction and yet be able to keep the area relatively free from unwanted electrical activity generated during accessory movements of the body. In order to find such a site three problems must be investigated:

1. Which muscle provides the best sites?
2. Is there some predictable spatial pattern of electrical activity generated by the contraction of each muscle?
3. Is there some predictable spatial pattern of electrical activity generated during accessory movements of the body?

Materials and Methods

Data recording–The Grass Polygraph is a writing oscillograph which can be used to record the EMG, EKG, and EEG. It is used in this problem to measure electrical potentials generated by muscle contraction. The simple EMG presents a recording of each individual electrical event, i.e., a change in potential for each firing of each motor unit. Since surface electrodes are used, the input consists of potentials from many motor units; i.e., many positive and negative deflections are all recorded, and the EMG has many sharp peaks and valleys. This wave-form is difficult to analyze because it fluctuates so rapidly. The integrator cir-

cuit takes all negative deflections and makes them positive, and these are summed with the positive deflections or potentials. Thus the integrated EMG sums the positive and negative potentials and smooths the recording, making it useful for coupling with mechanical devices, because it is more precise and offers graded responses up to a maximum.

Electrodes–10 Beckman biopotential electrodes were used to record the surface muscle potentials. The Grass Polygraph was equipped with six channels, each of which received input from any two of the 10 electrodes, and which recorded the integrated EMG from the inputs of these two electrodes. A multiple channel selector attached to the Polygraph allowed the connection of any two of the 10 electrode inputs to any of the integrator channels; hence, without changing the position of the electrodes the inputs to each channel could be altered, thus changing the site measured by a particular channel.

The integrated EMG is displayed as a deflection of the marking pen from the baseline; the Polygraph is calibrated in such a manner that a 0.5 cm. deflection of the marking pen corresponded to an input potential of 100 μV.

Subjects–Subjects for this research were 13 men and eight women from the staff personnel of the Physical Medicine Department. There was no preference in selection of subjects on the basis of sex, age, or any other criteria.

Mapping procedure–A grid showing x and y coordinates was drawn with a wax pencil on the skin overlying each muscle to be tested. Beckman biopotential surface electrodes were then taped at desired locations on the grid. A small amount of Beckman Offner Paste was applied to the electrodes in order to decrease skin resistance. The subject was asked to contract the test muscle and then to perform various motions and activities, such as turning the head or coughing. The potentials for several pairs of electrodes were simultaneously recorded. The electrodes were then moved to new locations, and more recordings were made.

Standard electrodes–When the potentials for several pairs of electrodes are recorded simultaneously, it is clear that the values pertain to the same maximal contraction of the muscle. When a "maximal" contraction is repeated and recorded there is no guarantee that this maximal contraction is the same as the first. Therefore, one pair of electrodes was kept in the same position and used as a reference in determining a maximal contraction. Thus the subject can adjust the force of contraction (either maximal or submaximal) to produce a given potential at the reference electrodes throughout all the trials, assuring a nearly constant degree of contraction for each individual test.

Proportional control–The newest myoelectric devices are designed to operate in such a manner that they reflect the degree of contraction of the muscle used as a trigger. They respond to a given amount of elec-

trical activity produced by the muscle with a given degree of force of prehension. The device is adjusted to produce a maximal force when triggered by a maximal amount of electrical activity from the muscle trigger site, e.g., 600 μV. Therefore, if the muscle trigger produces only 300 μV, the hand will contract with only half the force. For any other submaximal electrial stimulus, the hand will move proportionally.

It was necessary to determine whether the subject could voluntarily produce various submaximal amounts of electrical activity by contracting his trigger muscle. He would need to produce these increments of electrical activity in order to control a proportionally responding myoelectric device. Included in the tests for each muscle was this test of proportional control. The subject was instructed to watch the recording pen as it registered the potential from the muscle he was contracting. He was to produce various amounts of electrical activity between the two reference electrodes, i.e., 100 μV, 200 μV, 300 μV, 400 μV, etc., up to the maximum amount. The electrodes over the other areas of the muscle recorded the potential under these controlled conditions.

Most of the muscle sites could be controlled to produce increments of potential. At some of the sites the order of the 100 μV potential stimuli as recorded at the standard electrodes was reversed or altered, but this did not mean that this site could not be used to control a proportional switch. At some sites the recordings of these 100 μV increment stimuli were all compressed into a 50-100 μV range, and it would be difficult for the myoelectric device to discriminate between such fine gradations. Clearly this was a hard criterion to evaluate.

Grounding, Electrode Orientation, and Electrode Separation–Subjects were grounded with a 2-cm. square plate on which EMG paste was applied to decrease skin resistance. The position for the ground varied for each muscle tested, but was constant for the series of tests with a particular muscle.

In preliminary tests, the exact electrode separation and orientation seemed to make little difference with regard to the amount of electrical activity recorded. These tests show that the largest (Fig. 1) potentials were recorded for an 8-cm. separation, but the magnitudes when using a 4-cm. separation were also large, and the convenience of using a 4-cm. separation outweighed any slight gain in magnitude. For separations greater than 8 cm., there was an artifact in the recording that resulted from a superimposition of an EKG recording onto our EMG recording. Therefore, a horizontal orientation with a 4-cm. gap between electrodes was chosen.

Muscle Mapping

The muscles chosen for the experimental work were trapezius, fron-

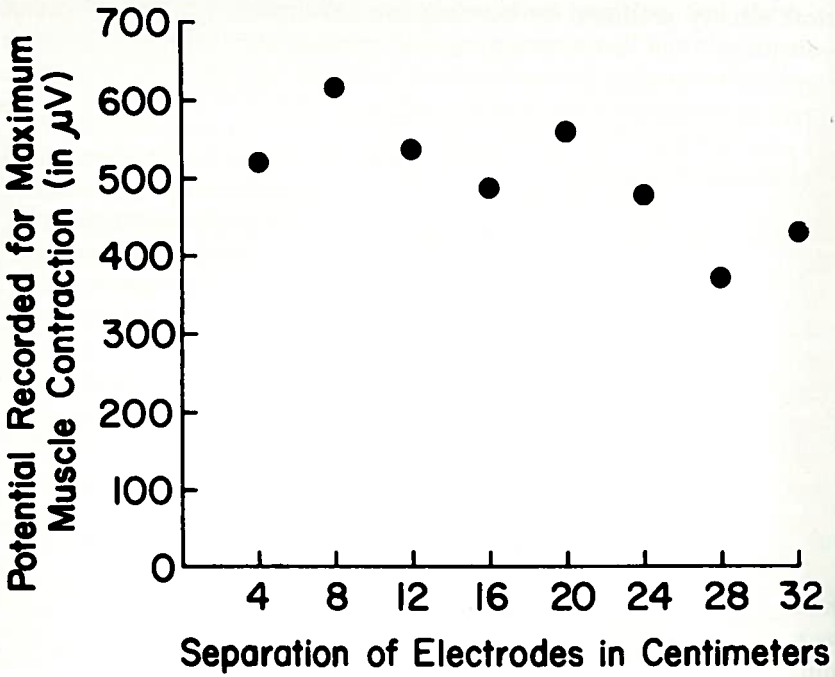

FIGURE 1

talis, and platysma. Each presented specific problems of coordinates and accessory movements. These are discussed serially below.

Trapezius Procedure

The upper trapezius was selected for testing because a quadriplegic patient with a lesion below the 4th cervical vertebra would still retain trapezius function. Electrodes were placed on the skin over the upper trapezius (Fig. 2) and a ground electrode was placed on the spine of the opposite scapula. The subject was seated in a wheelchair with his arm in an attached feeder device, which was adjusted so as not to assist the required arm movements (see Fig. 3). This experimental condition approximated the eventual clinical application, since the quadriplegic patient needing a myoelectric control for his hand orthosis is the type of patient who requires the assistance provided by a feeder device.

Since the upper trapezius acts to elevate and square the shoulders, these were the movements the subjects were instructed to perform—moving the shoulder up, moving it back, and a combination of the two. The accessory body movements investigated included arm, trunk, and head movements.

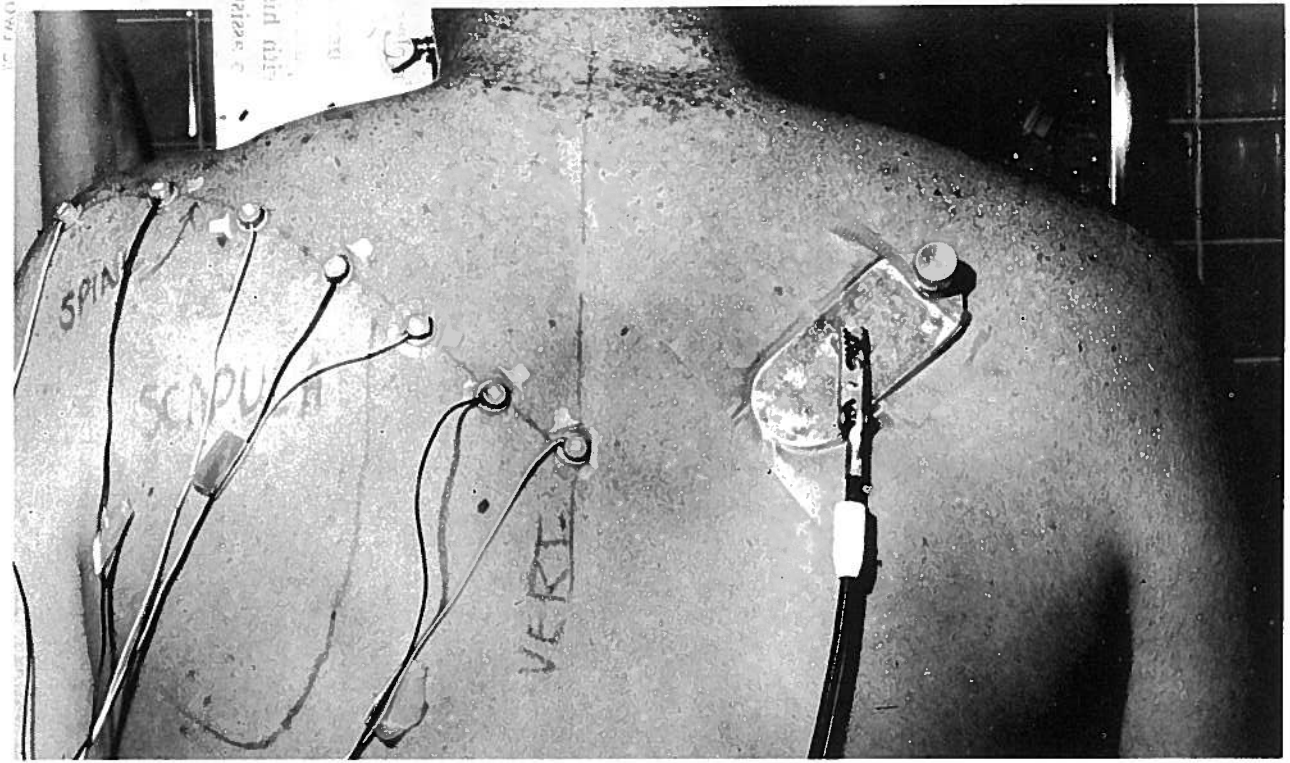

FIGURE 2.—The axes for orientation of the electrodes over the trapezius muscle.

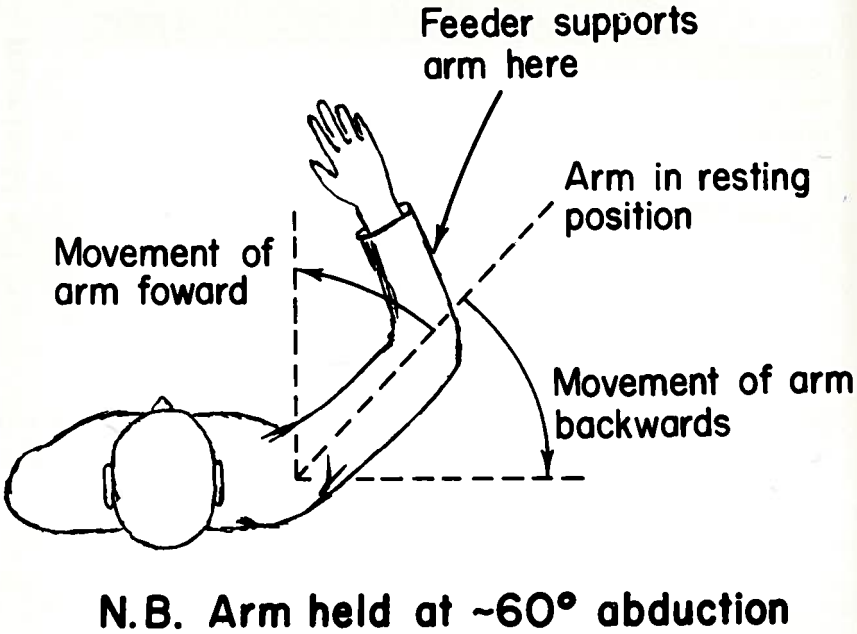

FIGURE 3

Results (see Fig. 4)

The recordings for the 5 subjects were widely divergent, making generalizations difficult. These variations were due to the great differences in muscle strength, size, and electrical activity, as well as to differences in the impedance between muscle and electrode because of changes in moisture, temperature, and thickness of skin and connective tissue.

In general it was found that the least of potential was recorded for electrodes placed more than 8 cm. cephalad from the x axis.

The movement of the shoulder up and back produced the largest and most adequate potentials for use in triggering a myoelectric device. These potentials recorded for the combined movement up and back were equal or greater than the sum of potentials for separate movements of the shoulder up or back. If necessary, either the movement up or the movement back could suffice.

Shoulder movements backward produced maximum potential at an area one-third of the distance between the lateral and medial aspect of the muscle. The peak response for raising the shoulder occurred midway between the lateral and medial borders.

Vigorous movements forward and back, as well as abduction of the arm, caused much undesired electrical activity, but a quadriplegic pa-

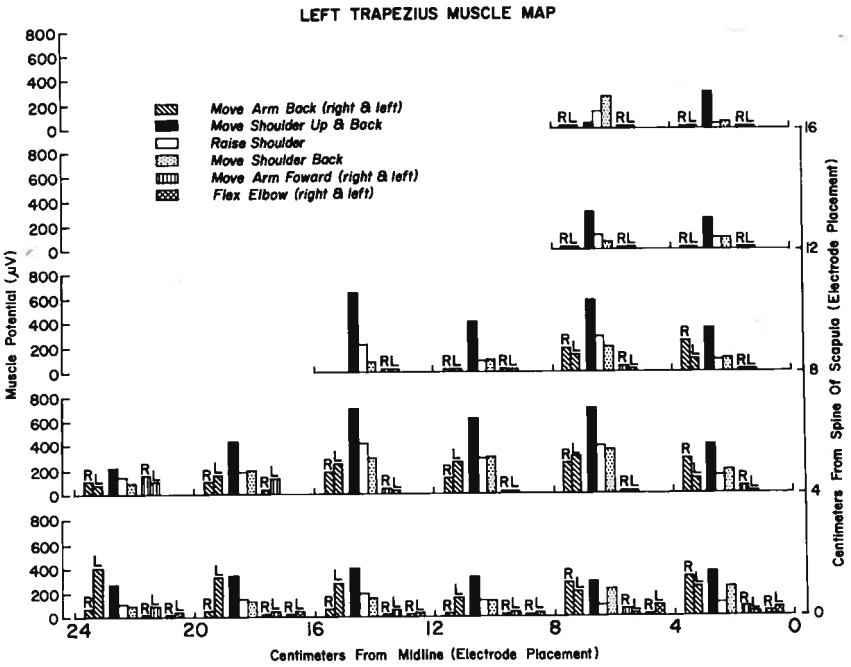

FIGURE 4

tient would not have the ability or the occasion to produce these movements, if his arm is supported by a splint.

Movements of the arm backward usually produced most activity near the lateral aspect of the ipsilateral trapezius. This could make this area unacceptable as far as unwanted electrical interference is concerned, if the orthotic device to be triggered by the trapezius is located on the same side as the myoelectric switch site. Hence, the overall number of good sites on the trapezius for a device worn on the same side of the body was 47 percent of those available, whereas 54 percent of the sites would be acceptable if the device were on the opposite side of the body from the motorized device. For many sites an inability to relax was demonstrated even though the subject was voluntarily relaxing. The head, trunk, and forward arm movements produced a maximum of less than 100 μV (the minimum needed to trigger the orthotic device), and would therefore not register or interfere with a myoelectric switch site.

Larger potentials were recorded for thin people, even larger than those measured on muscular people, probably because of the relative lack of adipose tissue which would impede electrical transmission from the muscle to the recording sites on the skin.

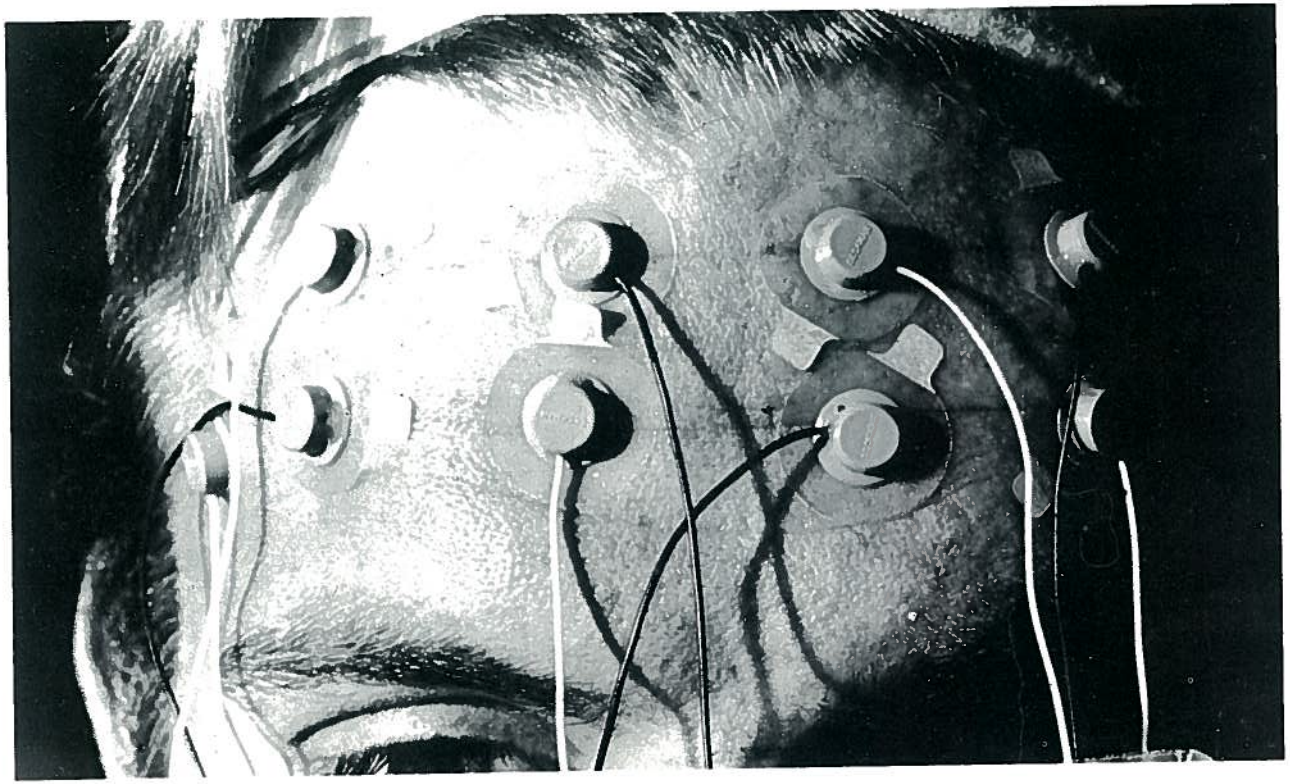

FIGURE 5.—The axes for orientation of the electrodes over the frontalis muscle.

Frontalis Procedure

The frontalis was mapped even though it was recognized that having electrodes taped to one's forehead would be cosmetically undesirable. These electrodes could perhaps be masked (for example by hair), or indwelling electrodes might some day be perfected.

The ground was placed on the back of the neck.

The frontalis acts to raise the brow, so the nine subjects were instructed to do this. Closing the eyes tightly and clenching the jaw were actions producing electrical interference (see Fig. 5).

Results (see Fig. 6)

The magnitude of the potential produced by frontalis contraction increases toward the periphery of the muscle, as seen in the muscle map.

The rows nearest the eyebrow (y=0 and y=2) were eliminated from consideration, because the orbicularis oculi muscle used in eye-blinking produced too much electrical interference. The potential from closing the eye is greatest not only in the lower aspects of the frontalis (nearer to the orbicularis occuli) but at the periphery. Potential from clenching the jaw is greatest at the periphery because of proximity to the temporalis.

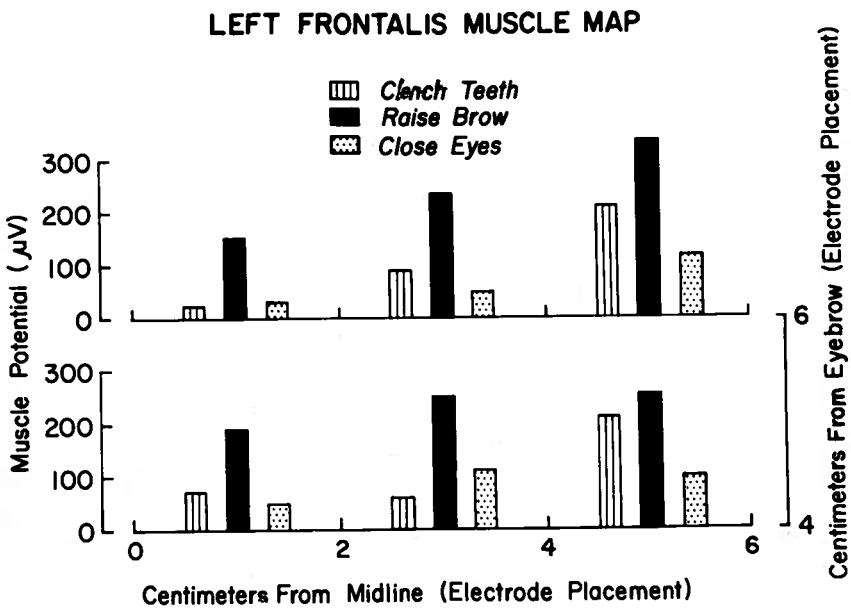

FIGURE 6

Although the central sites were more free of interference, they also produced the smallest desired potentials. Therefore, as a compromise

the best sites were judged to be generally halfway between the midline and the lateral edge of the muscle. Of all the sites tested, almost half (48 percent) were acceptable.

Platysma Procedure

The platysma muscle draws the corner of the mouth downward and widens the aperture. Activities performed by the five subjects included simple contraction of the muscle, smiling, clenching the teeth, chewing, swallowing, and head-turning. Activities such as talking, opening and closing the mouth, frowning, raising the eyebrows, and tilting the head back induced such a small electrical response in initial studies that they were omitted from most of the tests.

Results (see Fig. 7 and 8)

Results indicated that good control sites can be found all over the platysma muscle. Electrical interference from accessory activity is minimal. In all, 92 sites were tested, and 63 of the 92 (68 percent) were

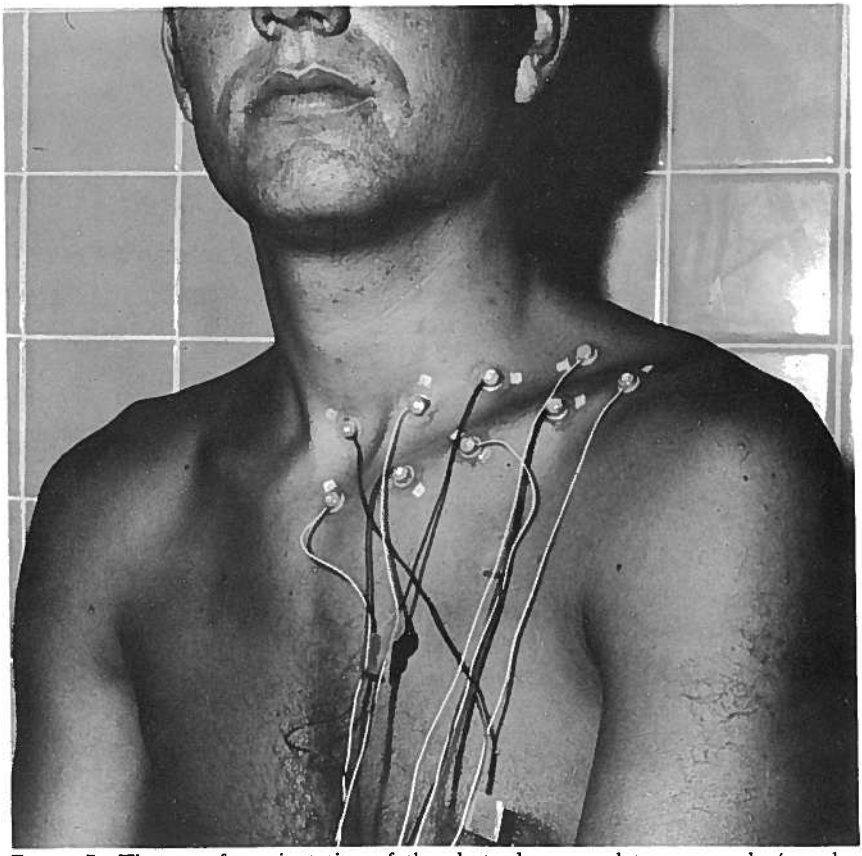

FIGURE 7.—The axes for orientation of the electrodes over platysma muscle (see also Fig. 8).

found to be satisfactory control sites according to the limits previously outlined.

No pattern relating the degree of electrical activity produced by simple contraction of the platysma with the y coordinate of the electrodes was observed in more than half the subjects tested. In two subjects the highest potentials were found in the bottom three rows (y=0, y=4, y=8), and in one subject the highest potentials were found in the bottom two rows (y=0, y=4).

Simple contraction of the platysma produced in all six tests a pattern of potentials such that in the bottom row only (y=0) the lowest values were found along the midline (x=0) and along the lateral edge (x=16).

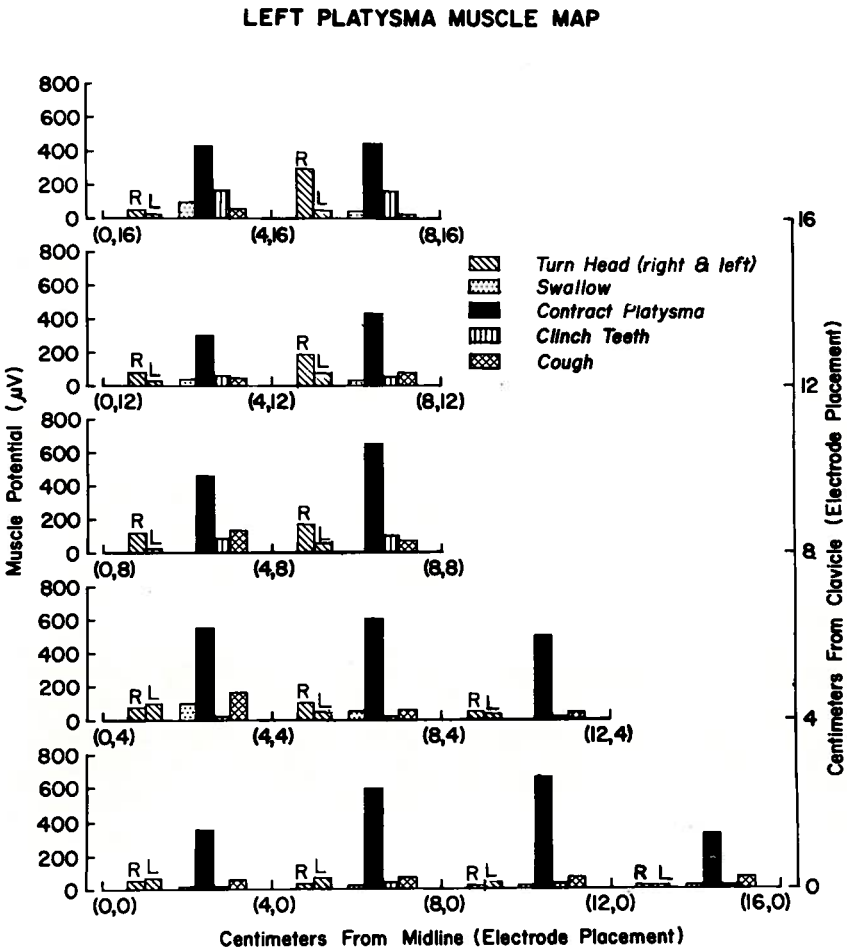

FIGURE 8

No relationship with the x coordinate was found in any of the other rows.

In five tests, head-turning was investigated. In three of the tests, turning the head in one direction caused greater electrical activity from the platysma on the opposite side from the direction of turn than from the same side, and this was more pronounced for sites over the cephalad aspect of the platysma. No such pattern was found with the other two subjects.

Smiling, clenching the teeth, chewing, and swallowing produced more interference in the top rows underneath the chin. No such pattern was found for coughing.

In four of the six tests the best control sites were in the bottom two rows.

DISCUSSION AND SUMMARY

It is clear that even when a standard channel was used in all tests, the data were not exactly reproducible from one test to the next at any given site. The least difference between two recordings from the same site was 12 percent.

The Grass Polygraph was the first source of error. The integrator cannot be linearly calibrated, and once calibrated the adjustment of the machine "drifts" after a short time. For example, when calibrated to produce a 1-cm. deflection with a 200 μV input, it produces a 2.75-cm. deflection with a 500 μV signal rather than the 2.5-cm. deflection predicted by a direct correlation between input and pen deflection. The source of errors lies in the diode of the integrator circuit, which modifies amplification of the recorded potential in a nonlinear fashion. To control from drift, repeated zero settings were necessary.

A second source of error lay in the assumption that identical contractions at one site, as indicated by equal potentials produced at the standard electrodes, implied identical contractions for all sites. Actually there was no guarantee that a muscle produced proportional potentials at every site at the same time. In fact, some studies have reported that with practice a person can cause the contraction of only the portion of a muscle lying under the recording electrodes and as the subject repeats a muscle contraction he may subconsciously be learning to contract several muscle bundles in a muscle without contracting other muscle bundles as much as in the initial trials. Nevertheless, for the purpose of standardizing the test movements and increasing reproducibility of data, it was expedient to make the assumption that contractions were identical.

The platysma is a better muscle for a myoelectric switch than the frontalis or trapezius. The frontalis or trapezius could be used but only with certain modifications. Placing electrodes on the forehead over the frontalis would be cosmetically undesirable, and these electrodes would

need to be masked in some manner. Many of the potential sites in the trapezius muscle demonstrated an inability to relax, a period after each contraction during which there was a considerable amount of electrical activity recorded for 10-15 seconds, even though the subject was voluntarily relaxing his muscle.

In contrast, 68 percent of the sites tested on the platysma muscle were acceptable, and the best sites were located close to the clavicle, which would make hiding these sites under clothing very convenient. The platysma relaxes immediately, and with practice it can be triggered without much noticeable facial grimace. Some subjects were able to control each half of their platysma separately, suggesting that it might be possible to use two sites on the two halves of the platysma for triggering two modes of control of an orthotic device.

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