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ELECTRICAL AND MECHANICAL PROPERTIES OF NEW BODY CONTROL SITES FOR EXTERNALLY POWERED ARM PROSTHESES

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Lack of a sufficient number of independent body control sites presently limits prostheses functions to a series of sequential mechanical motions. The utility of an artificial arm would be increased significantly if the amputee could achieve simultaneous multiple function coordinated control. Technologically, this does not seem to present a great problem but it would necessitate coordinated independent control by the amputee over rate and position of each function of the mechanism. In present systems, functions must generally be executed sequentially with the result that the amputee must be constantly aware of where he is in the sequence.

Furthermore, sequential movements of this type look "robot like" and achievement of a better cosmetic appearance by motion coordination seems desirable.

The unavailability of adequate control sites is especially serious for extremely handicapped individuals, as for example, those with bilateral high above elbow amputations. Control site locations for these amputees are restricted to the muscles of the upper torso. Previous experience with utilization of lower trunk or lower extremity sites has indicated the general undesirability of such remote locations.

This group of people would accordingly receive the greatest benefit from an externally powered device since their available control sites usually show inadequate force-excursion characteristics for activation and prolonged use of standard prosthees.

Muscles suitable for control sites in the region of the shoulder girdle normally function as coordinated groups and any isolated action must be achieved by surgical method or by training techniques (1,2).

Since the majority of amputees seem reluctant to submit to further surgery, development of a suitable training technique for achieving functional muscle isolation seemed indicated. That reliable functional isolation is possible is well known. Certain types of athletes and dancers take great pride in displaying such skills.

Requirements for an acceptable body control site can be summarized as follows:

1. Be capable of voluntary graded contraction of a specified muscle for control acivation.
2. Be capable of voluntary inhibition of contraction of the same muscle for avoiding involuntary control activation.
3. Show reliable and adequate output characteristics to permit coupling to a transducer mechanism.

In order to obtain a preliminary indication of the mechanical and electrical output to be expected from a functionally isolated muscle, we undertook the following study. Ten athletes were selected for their ability to produce reliable isolated contraction of one or several muscles. Using 5 x 5 cm rubber, stamp, .5 cm grid lines were placed on the overlying skin. Amount and direction of grid distortion was intended to provide quantitative output data. We took 35 mm color slides and 16 mm motion pictures of a series of contractions. An example is shown in Figure 1.
(Slide 1 - Photographic Records of Muscle Isolation)

Quantitative assessment of the muscle bulges remained unsuccessful. Mapping problems as, for example, the projection of three-dimensional data on to a two-dimensional surface, and problems of skin elasticity precluded reliable data analysis. However, visual inspection of the motion picture films indicated the potential utility of these isolated bulges for control purposes. The bulges could be elicited reliably, deformations were easily discernible and the maximum bulge of any given muscle showed a characteristic direction of travel. Surface EMG records were obtained for the same muscle contractions. The raw data were rectified and smoothed. Successful isolation was defined when the peak activity of a given muscle exceeded a predetermined noise level and when activity in the other muscles which a given individual could isolate, remained below an equivalent individual threshold. Results showed that the reliability of an isolated contraction of a single muscle fell off rapidly if it was considered in relation to the activity levels in the other muscles to be isolated. Examples of the results are shown in Figures 2 and 3.

(Slide 2 - Probability of Successful Muscle - Isolation as a Function of Muscle Set
Slide 3 - Isolation Performance as a Function of Muscle Combination for Sets of Two Muscles)

The major conclusions of the study can be summarized as follows:

1. Reliable functional dissociation and coordination of two muscle sites can be obtained.

2. The best combination of two control sites on the same body site was one muscle on the arm or shoulder region and the other on the trunk.

3. All combinations of two sites are good when both sides of the body are used.

Since these data were based on untrained subjects, we felt it would be possible to achieve greater reliability of isolation by proper training techniques. (3)

Further experimentation also was directed toward development of other measurement techniques for obtaining reliable data on muscle bulge deformations.

Since no appropriate training methods seemed to exist, we developed a Binary Myoelectric Training System based on accepted psychomotor training principles (4).

Without discussing the electronic details of the apparatus, its functional characteristics can be described as follows

(Figure 4 shows the apparatus): Slide 4 – Picture of Myoelectric Feedback Apparatus.

A fiberboard torso serving as a training aid contains small lightbulbs at the muscle locations to be isolated. These bulbs are individually controllable and will be illuminated if the EMG output of the subject's muscle exceeds an arbitrarily preset "threshold" level of the bulb. In this manner, the task difficulty level can be raised without awareness by the subject. Immediate success-failure feedback is provided to him by the lighted bulbs. One subject group was trained by this technique only. A further training aid was given to a second subject group. These individuals received prior direct electrical muscle stimulation with a commercially avilable stimulator. The objective was to assess the value of additional proprioceptive feedback for isolation training.

The EMG records only served as a criterion for successful isolation because the utility of the electrical activity as a direct control input still remains highly questionable.

An immediately more practical approach for control is the utilization of a mechanical muscle output for prosthesis control.

An attempt was made to employ ultra-sonic echo measurements as a technique for assessing changes in distance between the bone and the overlying muscle mass. The results of these measurements showed that the change in radial distance between the bone and the maximum deformation is only 1 mm to 6 mm. The reason for this unexpectedly small change may be due to the measurement technique which requires contact between the ultrasonic probe and the skin when the measurements are made in an air medium. As to be expected, there was no correlation between amount of deflection and EMG signal strength for the same condition.

Further perfection of the ultrasonic technique and measurement of muscle deformations in a fluid medium which would not require direct skin contact with the probe, may ultimately prove to supply more reliable transducer input specifications.

Experimental data reduction for assessing the utility of the training technique and the possibility of creating several adequate control sites is still in progress. Some results are presented in Figures — Slides 5 - 17 — Experimental Results.

In general, it seems that the latissimus dorsi, the deltoid and the pectoralis muscles can be successfully trained with proper techniques. A remaining error level of about 10% at the end of the experiment, that is of simultaneous activation of the muscles which were to remain inactive, probably suggests that more than 10 training sessions may be necessary.

Individual session to session performance irregularities present another problem.

If with further refinement this method can be practically utilised for developing three functionally independent body control sites, the engineering problem of providing multi-function coordinated prosthesis control can be justifiably and vigorously attacked.

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