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SENSORY FEEDBACK PROSTHESIS USING INTRA-NEURAL ELECTRODES

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Summary

Transcutaneous carbon buttons and fine coiled wire electrodes permit direct electrical stimulation of the median and ulnar nerves in a below elbow (BE) amputee. Transducers to convert prehension force and position into modulated electrical stimulating signals are added to the prosthesis terminal device. Small signal processing and stimulating units are also to be incorporated into the prosthesis.

One amputee was implanted with the carbon-fine wire system. This system was designed for use with a shoulder-operated hook. A second implantation is planned for an amputee who will use a VA-NU Myoelectric Hand.

A number of waveforms and frequencies are being studied to determine which form of signal coding is best perceived by the amputee as an appropriate sensation. Preliminary results of this study are presented.

Introduction

Significant advances have been made in recent years in myoelectric control of prostheses.One of the fundamental problems, however, in their application is the lack of feedback to the user regarding position, touch and pinch force. Previous efforts to incorporate feedback into myoelectric systems include Mann and Reimers /1/ who developed a vibratory, cutaneous display of elbow angle to position the "Boston Arm". A sensory feedback system for a myoelectric hand prosthesis using electrical stimulation through skin electrodes was proposed by Beeker et al. /2/ and Kato et al. /3/.

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Clippinger /4/ made a significant contribution in providing sensory input to the amputee when he reported on a series of three patients in which the frequency of an electrical stimulus to a sensory branch of the median nerve was increased in proportion to pressure in a conventional prosthetic hook. The stimulus was applied through an implanted rf-coupled receiver connected to a wrap-around electrode. All three patients indicated they had the feeling of fist clenching as frequency was increased and subjectively felt that they had finer prehension of small and breakable objects.

Unfortunately, the hardware used by Clippinger cannot be used with conventional myoelectric control systems because the stimulus current would be picked up through the myoelectric pick-up electrodes and provide positive feedback to the myoelectric device. It was felt that this problem could be avoided by use of intraneural electrodes which have been tested in animals at our hospital. Using these electrodes, the threshold for stimulation is about 0.1 ma which is about an order of magnitude less than with wrap-around electrodes. It was believed this would allow feedback through the nerve without interfering with the myoelectric system.

The elements of the proposed scheme are shown in Figure 1. Electrical activity of muscles in the stump, activated by the brain, is detected by electrodes on the skin and used to control opening and closing of a Fidelity

Figure 1

VA-NU American Myoelectric Hand. Transducers have been added to the hand by the Advanced System Laboratory of the Veterans Administration to provide signals proportional to hand position and force during grasp. These signals are then coded and fed back to one or more nerves, and from there back to the brain, through intraneural electrodes. These electrodes are attached to carbon buttons placed in the skin to provide a stable, infection-free connection to external wires.

The intent of the current project is to fit two patients: one with a myoelectric hand and the other with a cable-operated hook. Two intraneural electrodes, placed in the median and ulnar nerves, will be used in each patient. Initially, the two feedback signals will be fed back through separate nerves, but one of the primary purposes of the project will be to determine the feasibility of various coding schemes to allow both signals to feed back through a single nerve.

At the time this paper was written, surgery had only been performed on the patient fitted with a cable-operated prosthetic hook. Three months post-operative results are presented for this patient.

Background

Before discussing the patient and the results of his surgery, a brief review will be presented of two developmental programs conducted at Rancho Los Amigos Hospital that have produced the basic feedback hardware. The two programs are a clinical application of permanent percutaneous electrodes and an investigation, using animals, into the feasibility of intraneural electrodes.

Percutaneous Electrodes

One of the percutaneous electrodes used at our hospital is shown in Figure 2. The bottom flange is surgically placed below the skin surface and the neck protudes through a small hole bored in the skin. Holes are provided in

Figure 2

the flange for tissue in-growth. Connection to external wires is made via samarium cobalt magnets placed in the neck of the percutaneous electrode and in the connector.

These electrodes are surgically placed under local anesthetic, the entire procedure requiring less than ten minutes. A hole is bored in the skin (Figure 3), and a small incision is made 2 cm to the side. The electrode is then introduced through the incision and the neck is worked up through the hole.

Figure 3

Over one-hundred percutaneous electrodes have been used during the last three years. They provide permanent infection-free passage and have been used both for chronic pain and motor control, for relief of contractures and joint ranging. Infection has occurred in some cases in which the tissue interface has been compromised by mechanical trauma. Electrode removal was required in some instances, but immediate antibiotic treatment was successful in others.

Intraneural Electrodes

Percutaneous wire electrodes have been used for many years for long-term recording of intramuscular EMG signals and for intramuscular stimulation /5/. In 1973, a project was initiated to determine the feasibility of using similar coiled wires, without the silicone rubber filling, for intraneural stimulation. The wire, with approximately one-centimeter at the end deinsulated, is crimped to a 30-gauge needle which is then inserted into and along the nerve for approximately one centimeter. The needle is then brought out and the wire is pulled through until the insulation is just inside the nerve sheath. The wire at the needle end is then clipped so the final configuration is as shown in Figure 4.

Figure 4

After two weeks, the motor threshold at 200 microseconds was approximately 0.1 ma. This was not found to change significantly during the next six weeks. Histology of the nerve and muscle showed no denervation, but some muscle specimens showed hypertrophy with small areas of slight atrophy. A fiber count one centimeter distal to the electrode was not significantly different than a count made one centimeter proximal to the electrode despite a significant hole due to the wire (Figure 5). Apparently, fibers are pushed aside but not destroyed as the needle and wire are inserted.

Figure 5

Clinical Application

Hardware

Technology from the two studies briefly reviewed above was combined to make the electrodes used in the present study. The active electrode (shown in Figure 6) is an intraneural electrode connected to a carbon button like that shown in Figure 2. In this case, the carbon is insulated from the wire and the magnetic connector, and it is used only to provide percutaneous passage.

Figure 6

The indifferent electrode (also shown in Figure 6) is identical except that a small carbon tip is attached to the end of the wire. The carbon tip is placed outside the nerve, but in close proximity to it.

Transducers were added to an APRL voluntary-closing hook for position and force feedback. As shown in Figure 7, temperature-compensated strain gages were placed on a flattened portion of the stationary hook to sense pinch force. The arm of a potentiometer placed inside the housing on the top of the hook was attached to the shaft of the movable hook.

Figure 7

Clinical Results

Three carbon buttons were surgically implanted in a BE amputee on January 27, 1975. Two of the buttons were connected to active electrodes, one placed in the median nerve and the other in the ulnar nerve. The third button was an indifferent electrode. All three buttons were placed above the elbow on the medial aspect of the arm. Figure 8, taken three months after surgery, shows the location of the buttons.

Figure 8

The electrical impedance has been relatively stable at 2000 ohms during the first three months. A strength-duration curve for minimum sensation is shown in Figure 9. Current levels are higher than those recorded in the animal study which was discussed previously. The reason for this is unclear.

Figure 9

The insertion of the electrodes was above the elbow, unlike Clippinger who placed his electrode below the elbow. An attempt was made during surgery to identify the sensory fascicles of both the median and ulnar nerves and to place the intraneural electrode in that region. Despite this, the patient, during stimulation subsequent to surgery, feels no sensation prior to activation of motor units in muscles innervated by the two nerves. At stimulation above this level he describes the sensation as a tightening of the muscles and when asked where he feels the sensation he points to the contracting muscles in the stump. This confirms the fact that a subject has no conscious awareness of excitation of large afferent fibers and that sensation, without accompanying muscle contractions, can only be obtained at stimulus levels high enough to excite cutaneous fibers.

In the next patient, who will be using a myoelectrically-controlled hand, the electrode insertion will be below the elbow, distal to motor branches to remaining musculature.

Test Results

The present patient was initially tested to determine how well he could distinguish differences in the sizes of a series of wood cubes. He was presented with a sequence of cubes of different thicknesses, ranging in 1/4" increments from 1/4" to 2 1/4", and asked whether the cube was larger or smaller than the previous one. Visual feedback was eliminated by a screen.

He was first tested with no electrical feedback to see how well he did with only the normal feedback he gets through the shoulder-operated cable. In all trials, he was correct 83% of the time. Excluding the 1/4" difference trials, he was correct 92% of the time which is very good. The percent error for all cube size differences is shown in Figure 10. At 1/4", the error percent

Figure 10

was 45% which is just below pure guess. However, he was able to distinguish all other differences very well. (The large error percent at 1 1/2" is due to the small number of trials conducted at the larger differences and the fact that the only two errors he made above 1" were at 1 1/2".)

Electrical feedback was then provided by setting the intensity of the stimulus to the median nerve at a comfortable level and varying the frequency with opening of the hook. After a suitable period of training, the test described in the preceding paragraph was rerun. There was no significant difference in the test scores with and without feedback. Our conclusion was that he gets enough feedback from the cable that he was ignoring the electrical feedback being provided. Further tests with alternate coding schemes are planned.

In addition to testing the patient's ability to use his hook with and without feedback, discrimination tests have been run to determine the patient's ability to discern changes in stimulus parameters. In these tests, two of the parameters are fixed (e.g., pulse amplitude and duration) while the third (frequency) is varied. A reference signal (a 1 second burst at a fixed center frequency) is followed by the test signal (a 1 second burst at a frequency other than the center frequency). The patient is asked to say whether the frequency of the test signal is higher or lower than the reference signal. This procedure is repeated for different frequencies bounding the center frequency. Repeated trials determine the minimum discrimination level, which is defined to be the frequency difference below which the percent of incorrect responses is greater than 33%.

Results at center frequencies of 15, 50 and 100 pps are compared with results of Prior /6/ for cutaneous stimulation in Figure 11. Results

Figure 11

are comparable, especially at 50 and 100 pps. It was also found that the subject had no ability to discriminate at 200 pps which also agrees with Prior. Discrimination tests for pulse amplitude and duration have also been initiated and will be reported at a later time.

References

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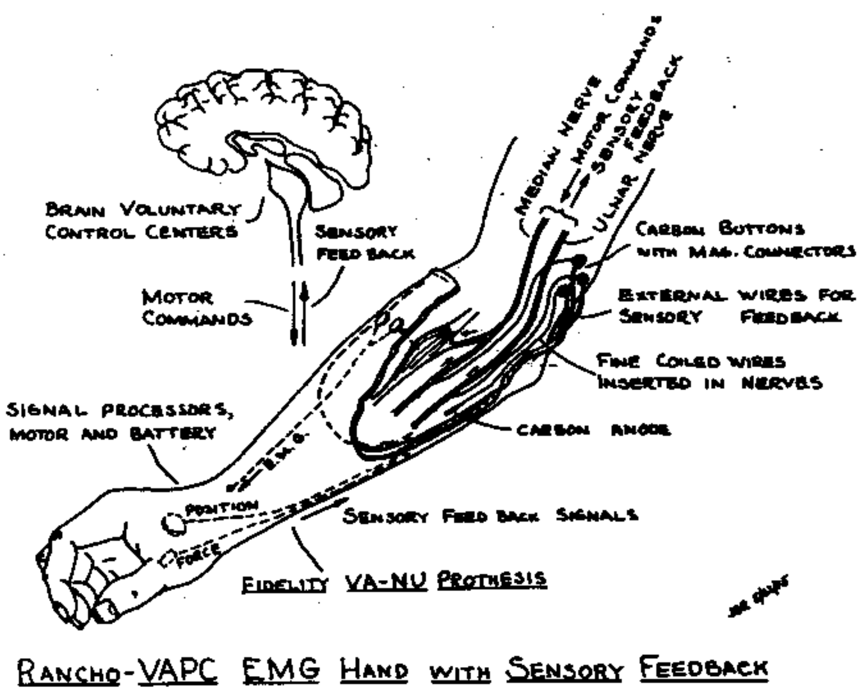


Fig. 1. Brain commanded myoelectric signals are used to control a VA-NU myoelectric hand. Transducers in the hand provide position and force information which is fed back to the brain through intraneural electrodes placed in the median and ulnar nerves. Carbon buttons placed in the skin provide a stable, infection-free connection between intraneural electrodes and external wiring.

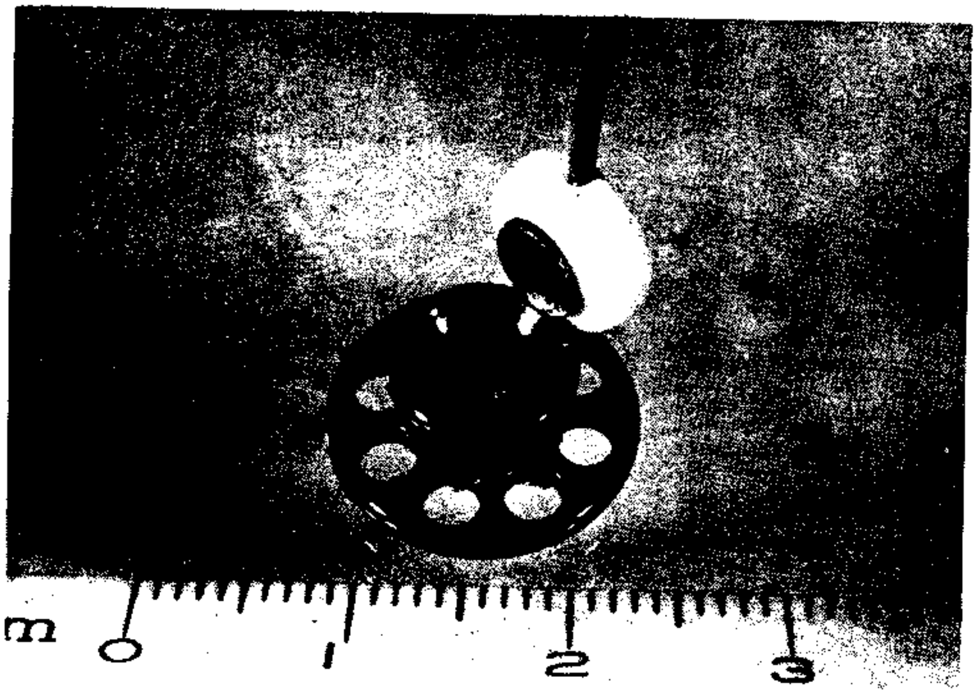


Fig. 2. Percutaneous carbon electrode with samarium-cobalt magnetic connector.

Fig. 3. Hole bored into skin for percutaneous electrode.

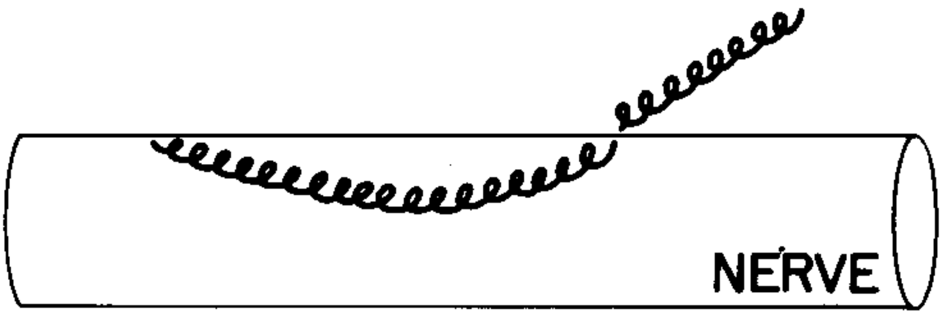


Fig. 4. Schematic drawing of an intraneural electrode. The approximately 1 cm length of coiled wire inside the nerve is deinsulated.

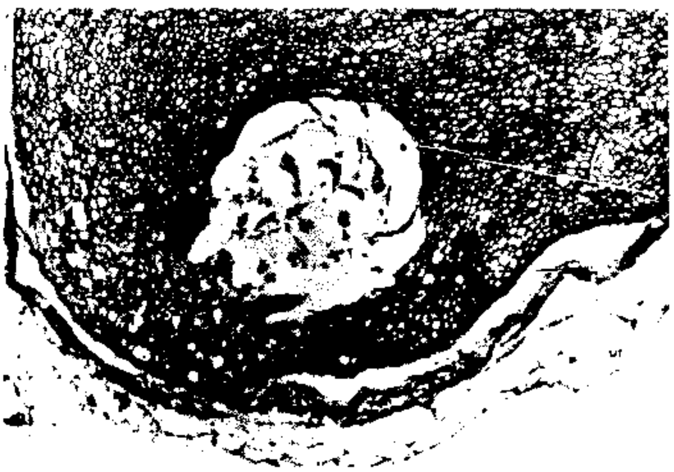


Fig. 5. Micrograph (luxol stain) of nerve section showing position of intraneural electrode as a hole in the nerve. This section shows very little intraneural fibrosis or demyelination around the electrode site

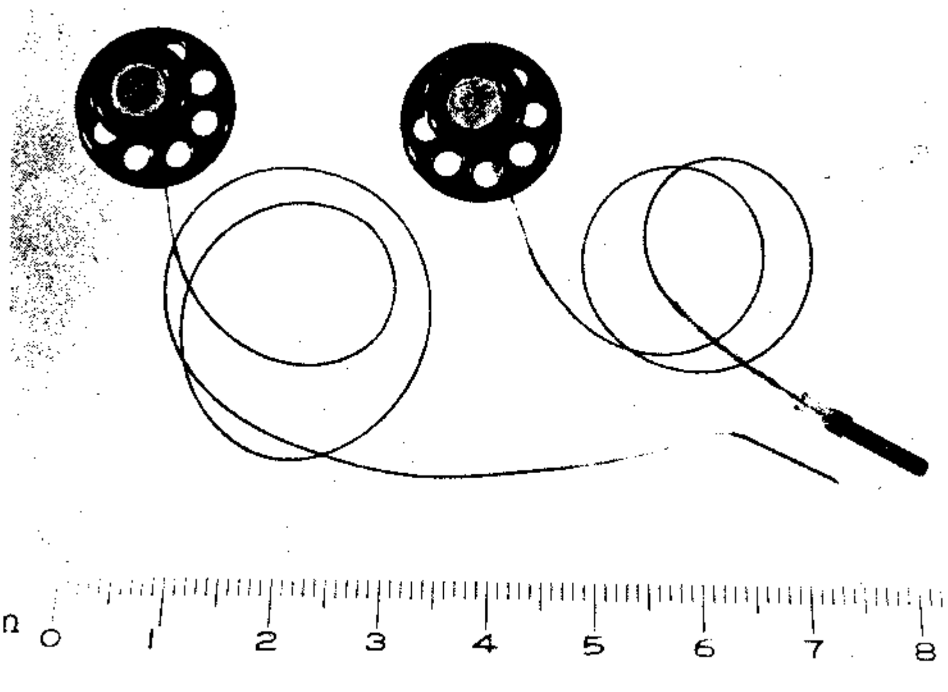


Fig. 6. Intraneural electrode connected to a percutaneous carbon button. The indifferent electrode is similarly constructed, but the electrode is a carbon rod placed outside the nerve.

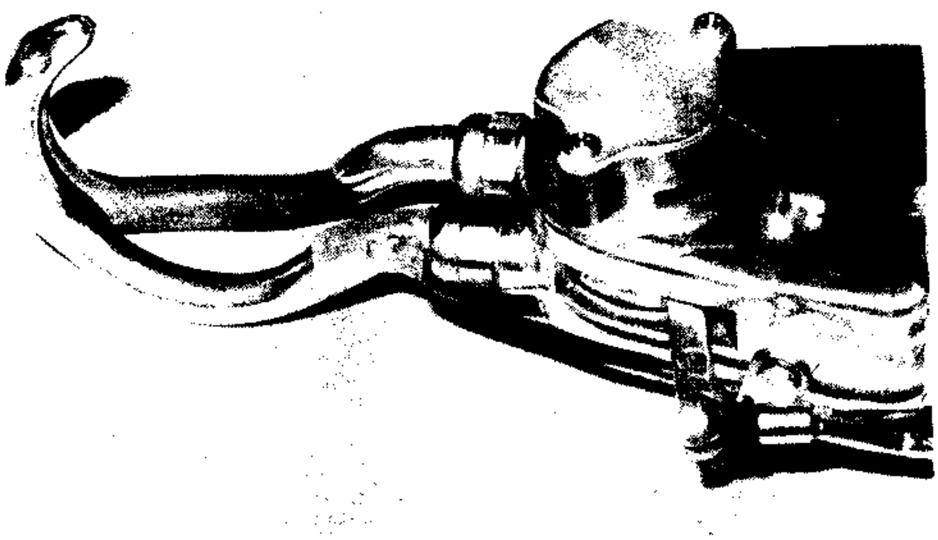


Fig. 7. Strain gages and potentiometer mounted on an APRL voluntary-closing hook for position and force feedback.

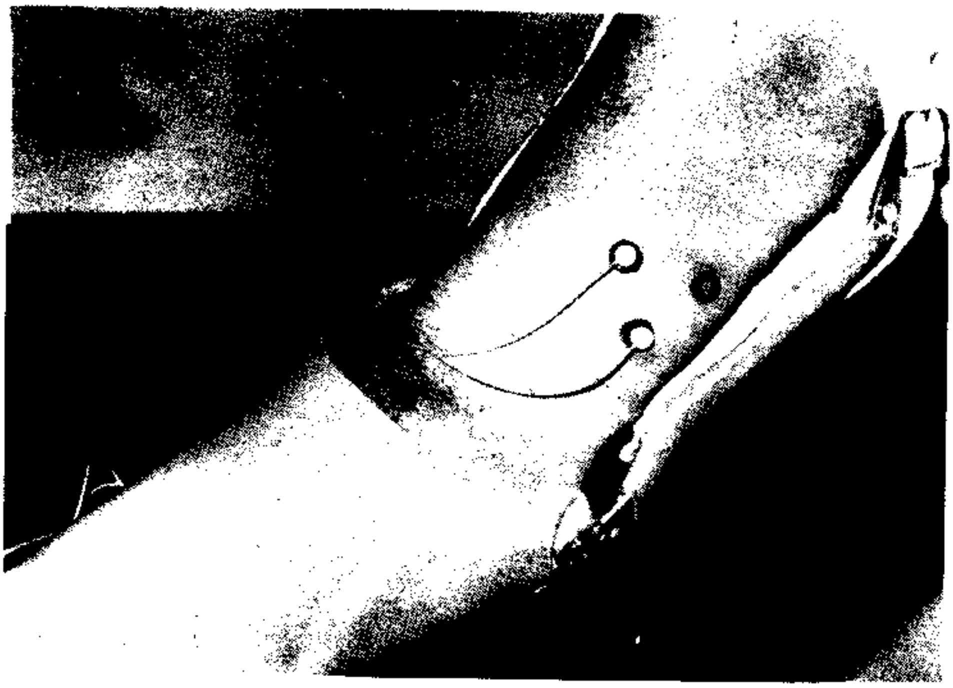


Fig. 8. Carbon buttons, three months after implantation, connecting intraneural electrodes to external wires.

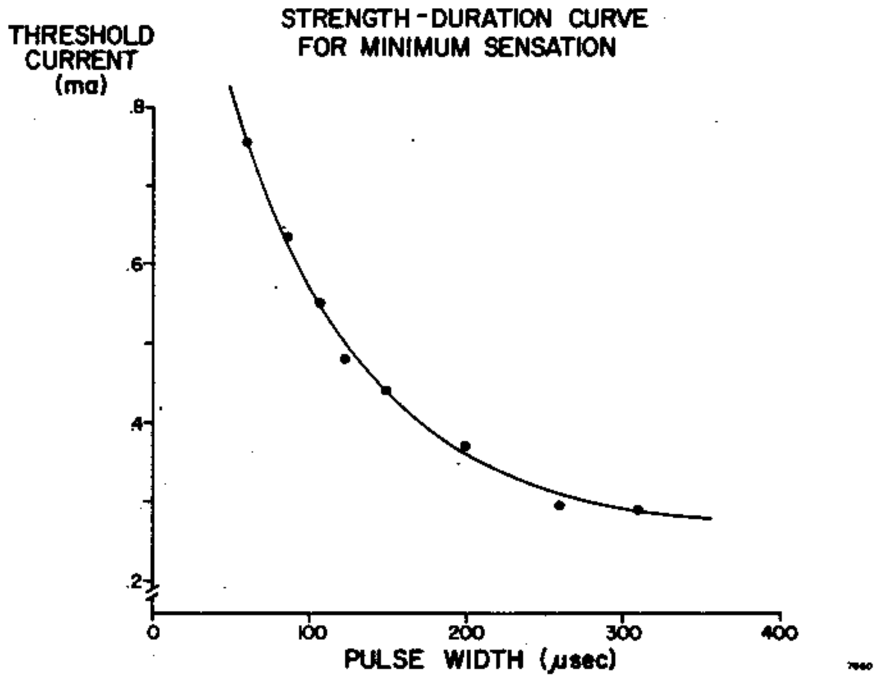


Fig. 9. Strength-duration curve for minimum sensation.

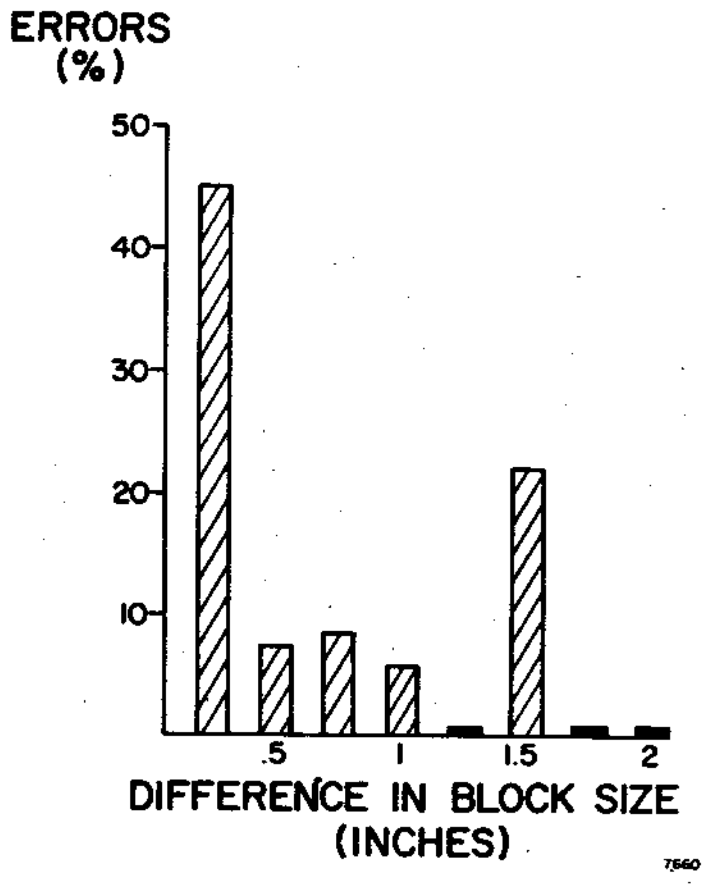


Fig. 10. Errors made by patient when asked to identify differences in cube sizes.

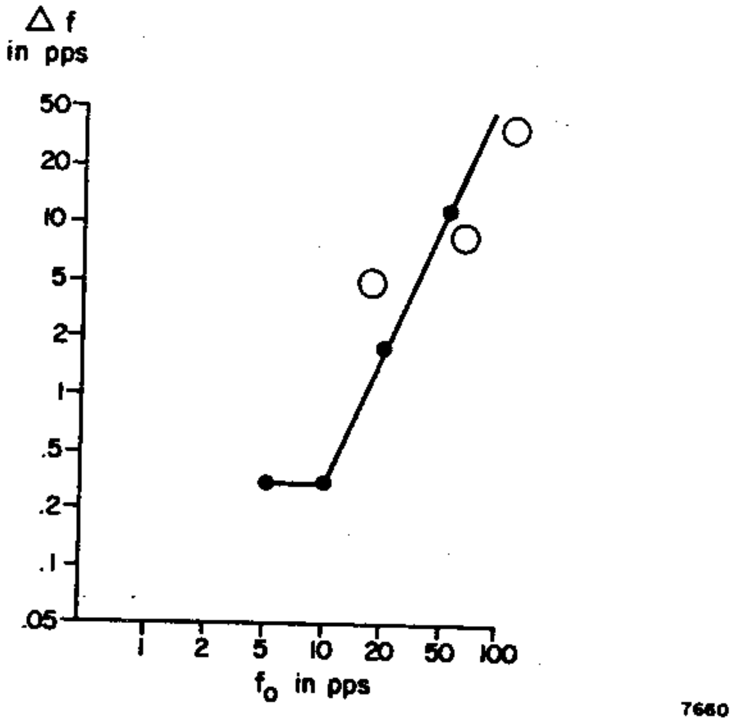
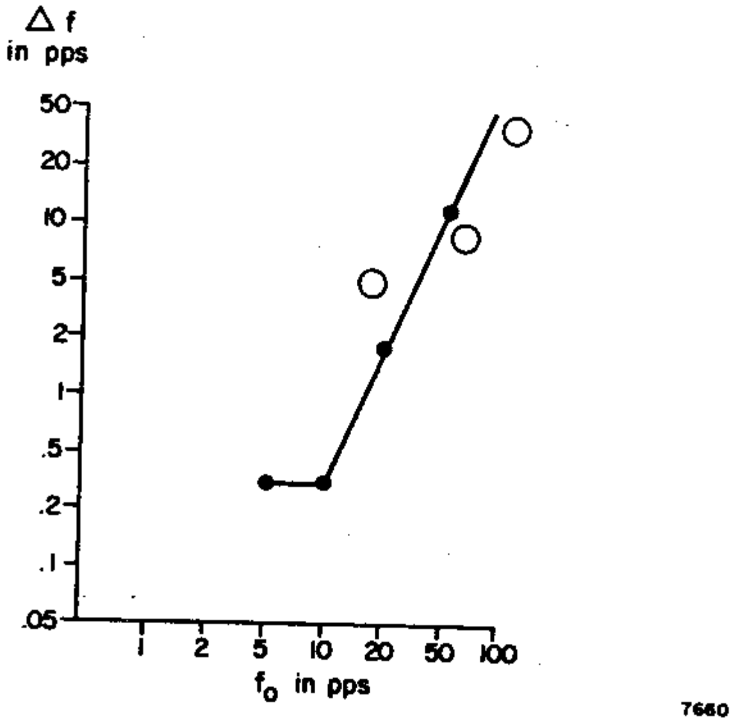


Fig. 11. Comparison with pulse repetition rate discrimination data from Prior /6 /, showing the difference in repetition rate which can just be detected (Δf) as a function of pulse repetition rate (f_o).



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