RECRUITMENT CHARACTERISTICS OF EPIMYSIAL AND BIPOLAR HELIX ELECTRODES

McNeal,[1] D.R., Baker,[2] L.L., Tu,[3] W.

[1]Rancho Rehab Engineering Program, Rancho Los Amigos Medical Center, Downey, California, USA.

[2]Department of Physical Therapy, University of Southern California, Los Angeles, California, USA.

[3]Formerly with the Rancho Rehab Engineering Program, Rancho Los Amigos Medical Center, Downey, California, USA.

ABSTRACT

Recruitment characteristics of bipolar helix nerve electrodes and epimysial electrodes implanted in seven cats were measured at four-week intervals. Data for nerve and muscle electrodes were qualitatively similar, but stimulation values for the epimysial electrodes were an order of magnitude higher than those required by the nerve electrodes. Recruitment properties of the helix electrode were indistinguishable from those of cuff electrodes previously studied. An interesting, but as yet unexplained, degradation of the recruitment characteristics of the helix electrode was observed in three cats.

KEY WORDS: recruitment, implantable electrodes, electrical stimulation

INTRODUCTION

Cuff electrodes have been used for many years in a number of clinical applications [1,2,3]. Their performance has generally been satisfactory, and their longevity has been quite remarkable -- cuff electrodes have been functioning in some patients for nearly 20 years. The rate of complications (nerve injury and infection), however, has been unacceptably high [4,5,6].

A more recent design, the Huntington bipolar bidirectional helix electrode (Fig. 1), may be an improvement over previous designs [7]. The helical coils permit a snug fit on the nerve without risking nerve compression, as do cuff electrodes that are sutured closed. The open pattern of the helix electrode may also allow more normal development of tissue and blood vessels around the nerve.

The purpose of this study was to record recruitment data for the helix electrode for at least 16 weeks after implantation. In this paper, these data are presented and compared with recruitment data for a cuff electrode from a previous study [8]. Recruitment characteristics of epimysial electrodes are also presented for comparison. Some of these data have been presented at the Osaka International Workshop on FNS, Osaka, Japan, November 1989 [9].

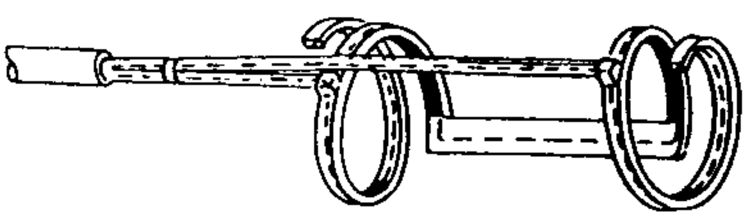


Fig. 1. Bipolar bidirectional helix electrode designed and fabricated by Huntington Medical Research Institutes, Pasadena, California.

METHODOLOGY

The nerve electrode used in the study was a bipolar bidirectional helix electrode (Fig. 1) fabricated by the Huntington Medical Research Institutes, Pasadena, California. Two platinum ribbon electrodes, 1 mm in width and separated by 7 mm, were mounted inside two 2 mm diameter helical coils made of silicon rubber. A special tool was used to assist in wrapping the helical coils around the nerve. The epimysial electrode consisted of a 1x2 mm platinum disk fixed to a 1 cm diameter sheet of silicon rubber reinforced with dacron. The ground electrode used with the epimysial electrode was a 9 mm diameter titanium disk coated on one side with silicon rubber. The epimysial and ground electrodes were fabricated to our specifications by a local manufacturer.

One electrode of each type was implanted in seven cats. The nerve electrode was placed on the left posterior tibial nerve, and the epimysial electrode was sewn to the right lateral gastrocnemius muscle. The ground electrode was placed subcutaneously in the right low back/abdominal region. The animals were maintained for 16 to 26 weeks and recruitment data were collected from both electrodes every four weeks.

The animals were anesthetized with an intramuscular injection of ketamine and maintained during surgery with halothane gas. Body temperature was maintained throughout surgery with a heating pad. The left popliteal fossa was exposed, the bifurcation of the sciatic nerve was identified and the nerve electrode was placed on the posterior tibial branch. The electrode lead was routed along the sciatic nerve through the sciatic notch to an incision on the lower back. The right lateral gastrocnemius muscle was exposed, and the epimysial electrode was placed and sutured at a location on the muscle surface that maximized muscle response to stimulation. The epimysial lead was passed subcutaneously to the incision on the lower back. The ground electrode was placed in the right low back/abdominal region and the lead was brought out through the back incision. The four connectors were placed in a silicon rubber pouch and placed in a subcutaneous pocket. Post-operatively the animals were returned to a restricted area and placed between warmed sheets to recover from the effects of anesthesia. Antibiotics were continued for five days following surgery or until evidence of inflammation was no longer apparent.

Testing was performed at four-week intervals. The anesthetic procedure used was similar to that described above. A single incision was made in the lower back to retrieve the pouch and provide access to the electrode lead wires. Animals were placed prone in a frame designed to stabilize their position and measure plantarflexion movements at the ankle. The hip and knee were extended, and the ankle was held at 90 degrees of flexion with velcro straps. The paw was strapped to an adjustable cantilever beam instrumented with strain gauges. Signals from the strain gauges were amplified, digitized and transferred to an IBM AT personal computer. The computer controlled a digital stimulator (Dagan Omni Pulse 9200), and a color graphics adaptor board and color monitor were used for display. Software was written to assist with data collection [10].

Recruitment data were obtained by fixing the pulse duration of monophasic constant-current rectangular pulses and varying pulse amplitude over the range between threshold and maximum recruitment. Isometric muscle twitches were used to minimize fatigue, and the peak value of the resulting twitch was recorded along with the corresponding values of pulse amplitude and duration. It has been found that recruitment curves derived from twitches and using plantarflexion moments match those generated with short tetanic bursts in the mid to upper part of the recruitment curve. The lower portion of the curve is shifted slightly to the right when using twitches, therefore the gain of the twitch-generated curve is higher in the low tension region [8].

RESULTS

We had very limited success in maintaining the bipolar helix electrode on the posterior tibial branch of the sciatic nerve. In 3 of the 7 animals, the required stimulation values were high during all test sessions, indicating that the helical coils had slipped off the nerve within four weeks of implantation. In the other four, there was a degradation of the recruitment curves beginning at 12 weeks in two animals, 16 weeks in the third, and 20 weeks in the fourth. In one of these four, the degradation was attributed to a broken lead to the distal electrode coil. In the other three, the degradation is not yet explained, but is described later in this section.

Our lack of success may be due in part to our limited experience with this electrode. The electrode can be pulled off the nerve quite easily, and it is imperative that tension not be developed in the lead wires as the limb is flexed and extended. Even though we checked this prior to closing up the incisions, the surgical implantation of this electrode may require more training than we had. Another factor, which is perhaps more important, is the location of the electrode. The posterior tibial branch can only be accessed in the space posterior to the knee, an area which is in constant motion when the cat is active. Since the animals were maintained in large cages and were not restrained, it is likely that the demands placed on the electrode were too great.

A set of recruitment data, that is typical of the four cats that started off with good data, is shown in Fig. 2. Normalized plantarflexion moments (percentage of maximum twitch moment) are plotted in Fig. 2a as a function of pulse amplitude at various pulse durations. Higher pulse amplitudes were required as pulse duration was decreased from 500 to 10 μs. Gain, represented by the slopes of the curves, decreased as pulse duration decreased. These data were replotted in Fig. 2b using a logarithmic scale for pulse amplitude. Plotted in this way, the slopes of the curves are essentially independent of pulse duration. This electrode had been implanted for eight weeks when these data were recorded.

Similar data for an epimysial electrode that had been implanted for 16 weeks are shown in Fig. 3. Our stimulator had a maximum pulse amplitude of 20 mA, so complete recruitment curves could not be obtained for the shorter pulse durations. The nerve and epimysial data were similar with the exception that the required stimulation values for the epimysial electrode were an order of magnitude higher than those required by the nerve electrode.

An alternative, convenient way to display these data was to plot pulse amplitude-duration curves at constant moments as shown in Fig. 4. These curves were created by reading the pulse amplitude required at each pulse duration (Fig. 2 and 3) to generate curves of constant normalized moments in 10% increments from 10 to 90%. The similarity of the families of curves for the nerve and epimysial electrodes becomes more obvious when shown on these amplitude-duration plots.

As mentioned previously, recruitment data which began with low stimulation values began to deteriorate with time in three cats. Data for one of these cats are shown in Fig. 5. The families of amplitude-duration curves (10-90% muscle tension) are shown at 8, 16, 20 and 23 weeks following implantation. Stimulation values were within the expected range through 16 weeks, but in Week 20 (Fig. 5c) it was not possible to generate maximum muscle tension at short pulse durations, even when pulse amplitudes were increased to 20 mA. At 23 weeks (Fig. 5d), further deterioration can be seen at pulse durations below 200 μs, and stimulation amplitudes have increased at all pulse durations. Similar changes were seen in the other two cats beginning in Week 12. The cause of these changes has not yet been determined.

DISCUSSION

The recruitment characteristics for the bipolar helix electrode shown in Fig. 2 is very similar to the data obtained in a previous study using a cuff electrode manufactured by Avery Laboratories [8], even though the two electrodes are quite different in design. In the bipolar helix electrode, the electrodes are platinum strips that encircle the nerve and are separated by about 7 mm. The back sides of the strips are insulated. In the Avery electrode, the electrodes are 1x2 mm platinum discs, separated by 6 mm, contained within a 3 mm diameter silicone-rubber insulating cuff that encircled the nerve. Despite these differences, it was not possible to distinguish these two electrodes on the basis of their recruitment characteristics; since the difference in recruitment characteristics between two helix electrodes may be as large as the difference between a helix and an Avery electrode.

The recruitment curves for the epimysial electrode are consistent with data presented by Grandjean and Mortimer [11]. In their paper, they show recruitment

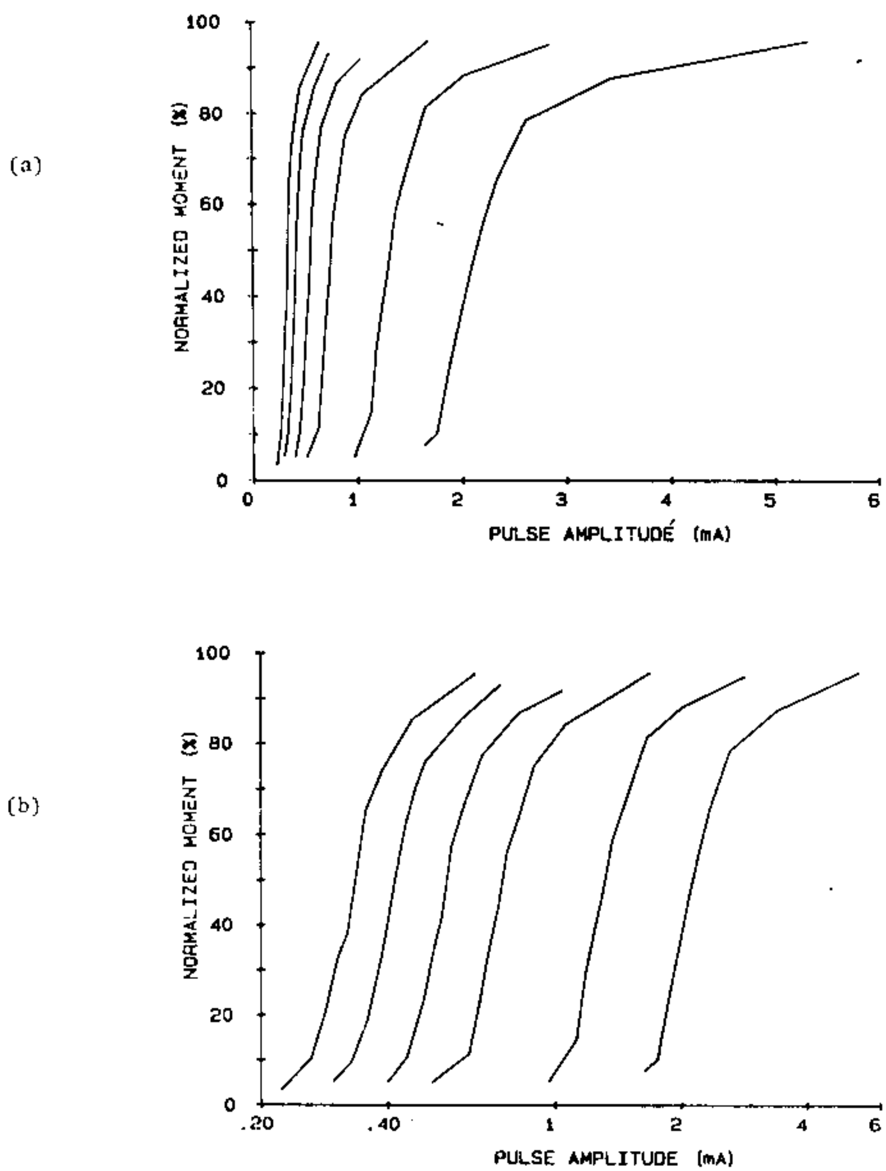


Fig. 2. Recruitment data for a 2 mm diameter Huntington bidirectional helical electrode with monophasic stimulation using a linear scale (a) and a logarithmic scale (b) for pulse amplitude. Pulse durations are 500, 200, 100, 50, 20 and 10 μs (left to right).

(a)

(b)

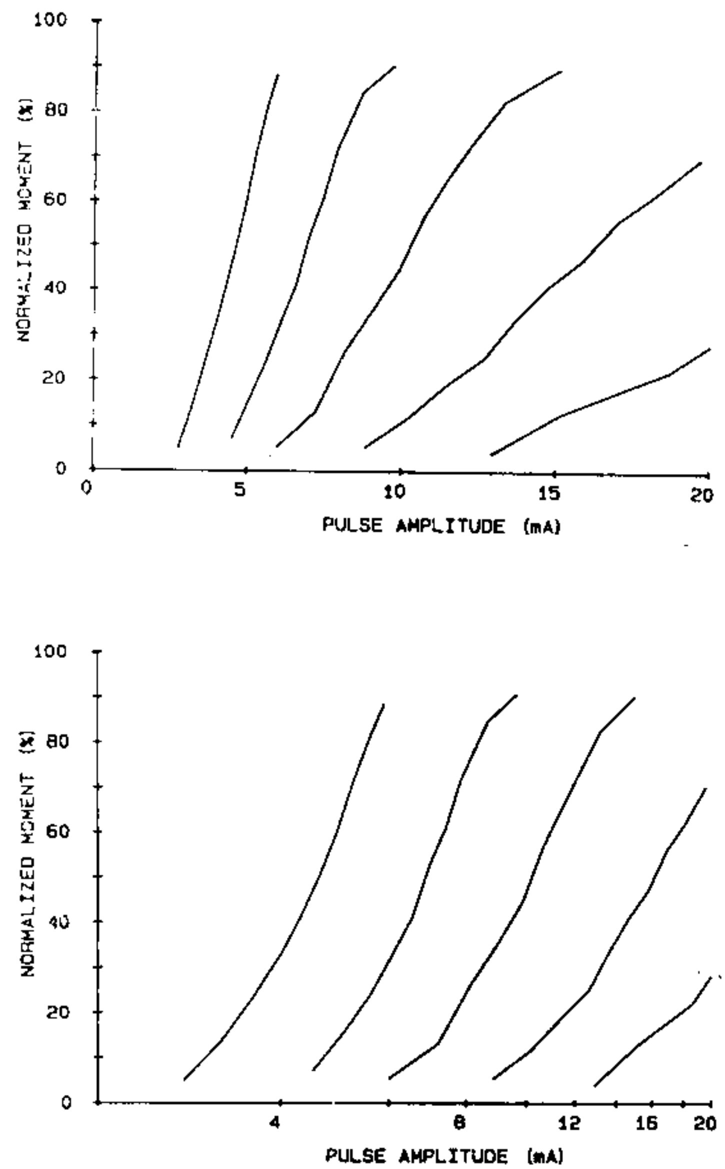


Fig. 3. Recruitment data for an epimysial electrode with monophasic stimulation using a linear scale (a) and logarithmic scale (b) for pulse amplitude. Pulse durattions are 500, 200, 100, 50 and 30 μs (left to right).

curves for monopolar epimysial electrodes placed on two muscles, the soleus and tibialis anterior. The recruitment curve for the tibialis anterior at a pulse duration of 100 μs is similar to the 100 μs curve shown in Fig. 3 of this paper. In both the tibialis anterior and the lateral gastrocnemius muscle (the muscle used in our study), the nerve enters the muscle on the underside of the muscle (the side opposite to where the electrode was placed). Grandjean and Mortimer showed that the recruitment curve for an epimysial electrode placed on the soleus muscle more nearly matches the recruitment curves for nerve electrodes (Fig. 2). This happens because the nerve enters the soleus muscle on the upper side of the muscle, and the epimysial electrode is therefore in nearly direct contact with the nerve.

The deterioration of the recruitment characteristics observed in three cats (Fig. 5) is not yet explained. It may be an indication of early axonal degeneration, but histological studies of this nerve did not reveal any significant evidence of injury to the

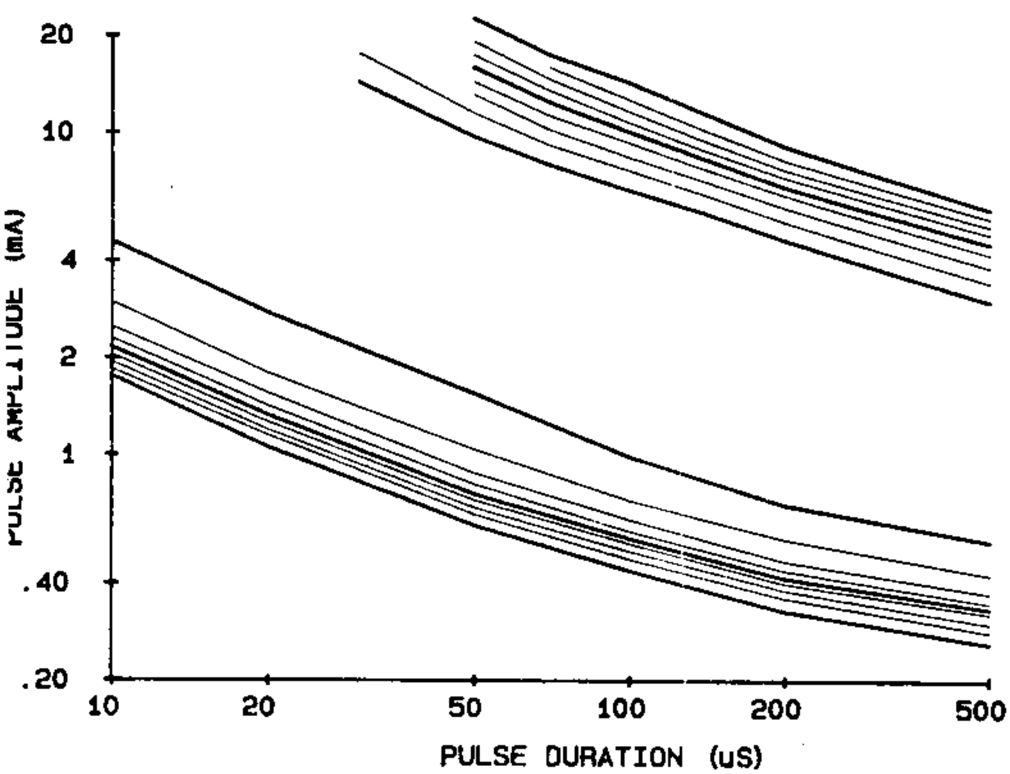
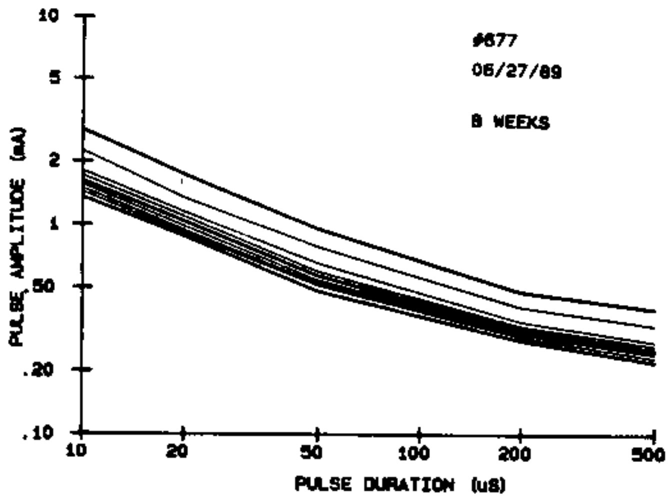
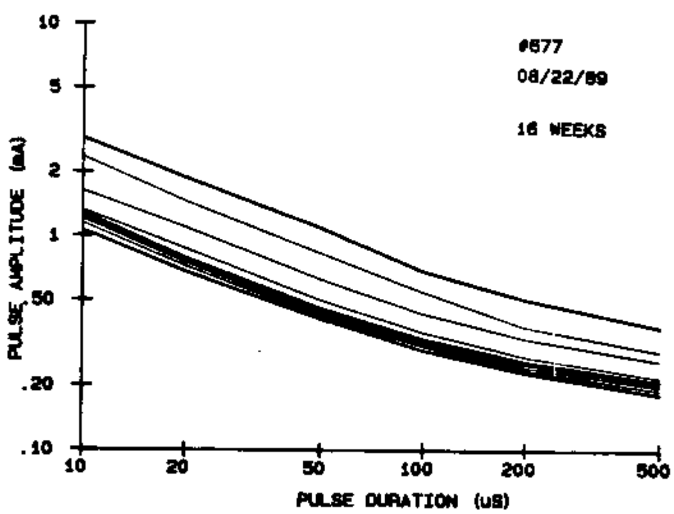


Fig. 4. Amplitude-duration curves at constant muscle tension ranging from 10 to 90% of maximum (10% increments) for nerve (lower set) and epimysial (upper set) electrodes.

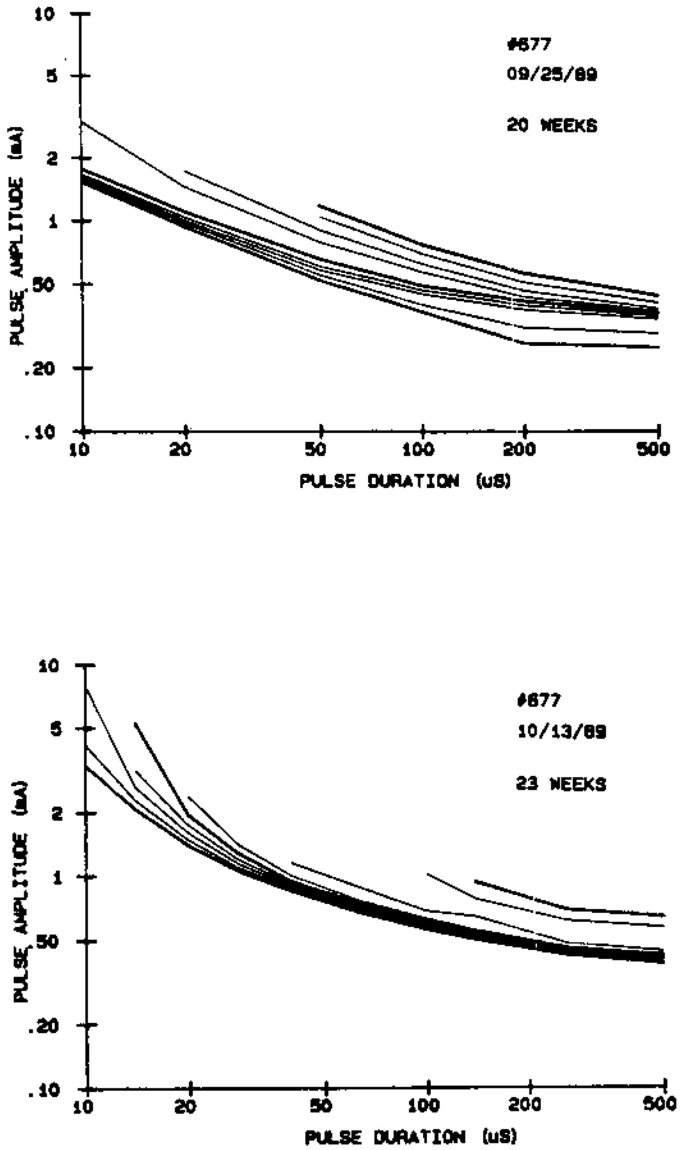


(a)



(b)

Fig. 5. Amplitude-duration curves at constant muscle tensions (10-90% of maximum) for a helical electrode at 8 weeks (a), 16 weeks (b), 20 weeks (c) and 23 weeks (d). (continued on next page)

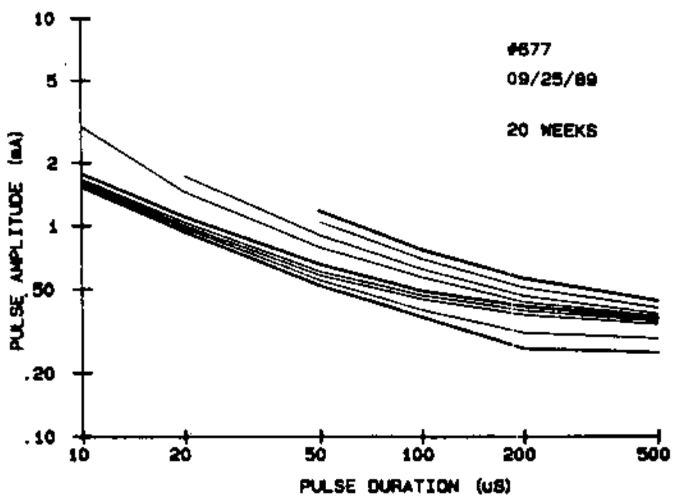


(c)

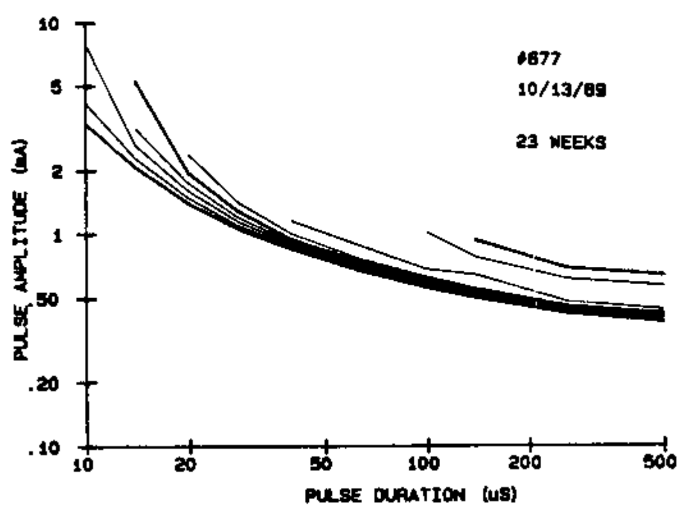
(d)

Fig. 5. (continued)

nerve axons. If the axons were compromised by the presence of the electrode, the changes were too subtle to be detected through routine histology. Additional studies



(c)



(d)

Fig. 5. (continued)

nerve axons. If the axons were compromised by the presence of the electrode, the changes were too subtle to be detected through routine histology. Additional studies