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COMPARISON BETWEEN MONOPOLAR AND TRIPOLAR CONFIGURATIONS IN CHRONICALLY IMPLANTED NERVE CUFF ELECTRODES

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ABSTRACT

Nerve cuff electrodes have been shown safe and able to activate selectively specific fascicles in a nerve trunk. Selectivity has been shown using a cuff with four radially placed tripoles thus requiring twelve contacts and twelve lead wires. This study evaluates a simplified cuff electrode, consisting of four radially placed monopole electrodes, requiring only four lead wires, and compares the results to the tripolar electrode configuration. Experiments were performed on two cats, each with an electrode that was implanted for over six months. Results from a correlation analysis and a torque vector likeness measure indicated that the recruitment characteristics of the two configurations were similar in 6 of 8 cases.

INTRODUCTION

Motor function in paralyzed persons may be restored by electrically activating the motor nerves of paralyzed muscles. Present motor prostheses employ surface electrodes, epimysial electrodes or intramuscular electrodes. Surface electrodes, although the least invasive, suffer from lack of selectivity and poor repeatability. Both epimysial electrodes and intramuscular electrodes require at least one electrode for each muscle desired. These muscle-based electrodes are also subject to material fatigue failure and displacement due to repeated muscle contraction. Nerve cuff electrodes, however, can be implanted in areas of low mechanical stress. A 12 contact cuff, (four radially spaced tripoles), can activate selectively different regions of a peripheral nerve trunk to recruit individual muscles [1]. This technique of selective activation is promising for controlling many muscles, as is required by a functional motor prostheses, with one cuff implant.

Present technology, however, lacks the ability to fabricate a lead and connector for this 12 contact cuff that is suitable for human implantation. To explore the potential of using the multicontact configuration in humans, we have conducted experiments with a simplified cuff. This simplified cuff contains four radially distributed monopoles, which have similar current distribution to the tripolar configuration [2].

METHODS

Two cats, each implanted with a twelve contact spiral nerve cuff electrode on the right sciatic for 28 and 32 weeks, were used. The cuffs were sized to the nerve diameter such that the tripoles, at the cuff's final resting position, were spaced at 90° intervals around the circumference of the nerve.

Stimulation consisted of biphasic current pulses with a cathodic phase of 100 μsec. In the tripolar case, these current pulses were sourced at two anodes located longitudinally on either side of the cathode where the current was sunk. For monopolar stimulation, the anode was a hypodermic needle placed subcutaneously on the back of the neck.

Isometric twitch torques were recorded using a force transducer attached to the cat's paw. The limb was oriented parallel to ground, with the hip, knee and ankle joints set to 90° flexion. The moments about the ankle were calculated for plantar/dorsi flexion, internal/external rotation, and inversion/eversion.

Two comparison techniques were employed. The first was linear correlation analysis of torque components generated by tripolar and monopolar configurations. The data from each configuration was normalized by threshold. The R^2 values, calculated from a regression line fit to plots of each torque component, was used as a measure of similarity of recruitment.

The second technique was a likeness measure based on the functional output of the muscles. The data was normalized in each direction to the maximum twitch force found in that direction. A cubic spline, fit to the data, was used to represent the curves. A comparison between two curves was made by taking each point on one curve and finding the nearest point on the other curve. Based on the Euclidean distance between these two points a measure of the likelihood that these two points are equivalent was assigned. By summing these values of likeness for every point on a curve and dividing by the number of points, results in a value of how much one curve can be spanned by the other curve. A value of 100% means that any point on the second curve can be achieved by the first curve.

RESULTS

Recruitment curves, showing plantar flexion plotted against current, for both monopolar and tripolar configurations are shown in fig. 1. Monopolar (solid lines) and tripolar (dotted lines) configurations are paired and labeled: 0°, 90°, 180°, and 270° according to their relative positions around the nerve. Monopolar recruitment curves are found to have the same or similar shapes as the tripolar curves, only shifted to lower levels of current. A shift in current is not of primary interest, but rather, we are interested in whether the two configurations can achieve the same recruitment patterns regardless of current level.

The current shift was eliminated by normalizing the data to threshold for correlation analysis. The R^2 values calculated are shown in table 1, along with the mean R^2 value for the three directions. Based on these R^2 values, 6 of 8 of the monopole/tripole pairs show a similarity (R^2>0.8).

A second method was used to compare the functional difference between the two configurations. Functional output of the limb can be represented in a space which is comprised of the three dimensions designated by plantar/dorsi flexion, external/internal rotation and inversion/eversion. Two sets of data from each cat are replotted in fig. 2, showing a 2-D representation of the torque vectors generated by the different configurations. This figure demonstrates the similarity of monopolar and tripolar stimulation with respect to the torque vectors generated at the ankle. Using this moment space representation, a comparison of the curves from monopolar and tripolar stimulation was made using the likeness measure.

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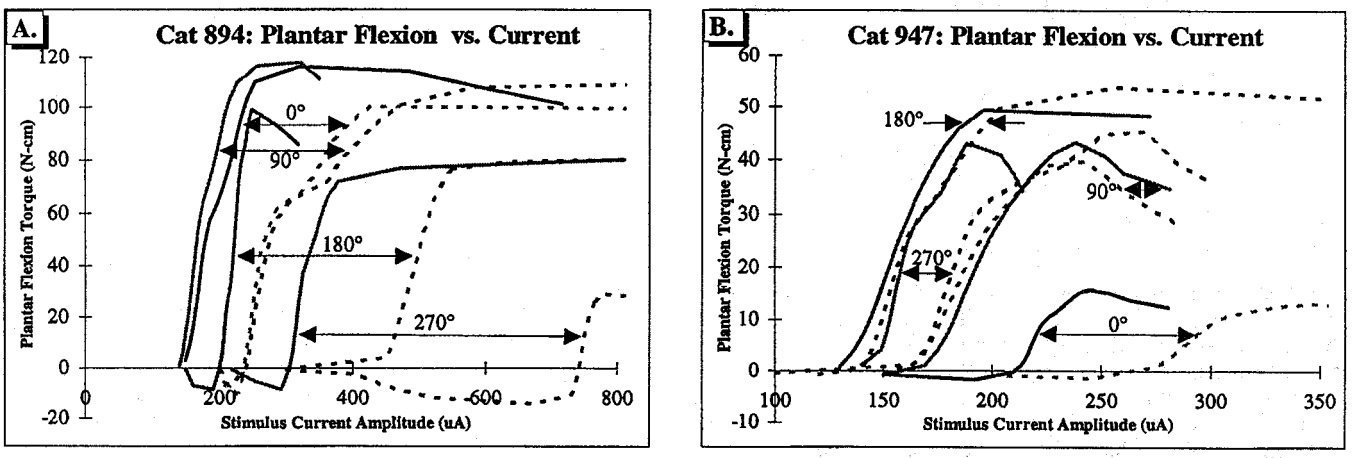

Figure 1 - Graph of recruitment curves, plantar flexion moments verse current amplitude, in A. Cat #894 and B. Cat# 947. These were acquired by monopolar and tripolar stimulation at 90° increments around the nerve truck. Notice how the tripolar stimulation, shown by the dotted lines, is a shift to the right from the monopolar stimulation, shown with solid lines.

The results of performing the likeness comparison for monopolar and tripolar configurations, for each contact, are shown in table 1. The results show that the likeness ratings of six out of eight of the contacts are very high while the other two, the 180° and 270° positions on cat# 894, are not as high. This is exemplified in fig. 2 by the lack of overlap between the monopolar and tripolar trajectories for these two positions. Although for cat# 947, the trajectories of the monopolar and tripolar configurations at position 0° overlay each other in fig. 2, the likeness measure indicates a low degree of similarity. This apparent discrepancy is a result of the third dimension, inversion/eversion, which is not displayed in fig. 2, but is accounted for in the calculation of the likeness measure.

Nerve Position	Correlation Analysis				Likeness Measure	
	Plantar Flexion R^2	External Rotation R^2	Inversion R^2	Mean R^2	Tripole ↓ Monopole	Monopole ↓ Tripole
Cat# 894						
0°	0.9685	0.9579	0.7485	0.8916	80.6 %	89.5 %
90°	0.9217	0.8031	0.7342	0.8197	85.5 %	99.4 %
180°	0.9968	0.6006	0.9718	0.8562	17.5 %	11.6 %
270°	0.1452	0.1149	0.5719	0.2773	22.7 %	19.2 %
Cat# 947						
0°	0.8272	0.9150	0.9631	0.9078	55.3 %	51.6 %
90°	0.9564	0.9638	0.9493	0.9565	71.3 %	96.1 %
180°	0.8648	0.9722	0.9533	0.9301	95.8 %	99.9 %
270°	0.6515	0.9170	0.7457	0.7714	99.8 %	94.0 %

Table 1 - Table of both R^2 values of current multiples and likeness values between monopolar and tripolar configurations for each position around the nerve trunk.

CONCLUSIONS

The torque vectors generated by monopolar and tripolar electrode configurations were measured and quantitatively compared. The monopolar configuration was found to emulate the tripolar configuration in six of the eight cases. In one case, tripolar stimulation generated extended dorsiflexion recruitment before spillover, while monopolar stimulation did not. In the other case, the monopolar configuration generated dorsiflexion before spillover while the tripolar configuration did not generate any dorsiflexion. The results of the correlation analysis agreed with the results of the likeness measure in 6 of 8 configurations. The difference between the two methods is that the correlation analysis is affected by the gain of the recruitment curve while the likeness measure is not. The results of both comparison methods indicate that monopolar stimulation can generate almost equivalent selectivity with only four lead wires.

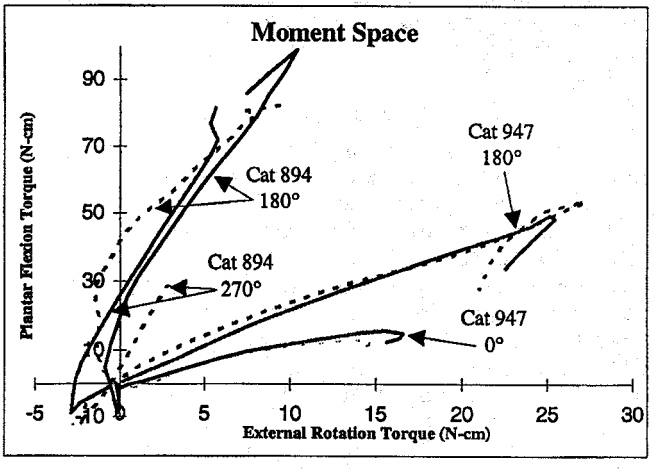

Figure 2 - Graph of recruitment curves from two cats, in moment space, plantar flexion verse external rotation, acquired by monopolar and tripolar stimulation at 90° increments around the nerve truck.

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[1] Veraart C., W.M. Grill, and J.T. Mortimer, "Selective Control of Muscle Activation With a Multipolar Nerve Cuff Electrode," IEEE Trans. Biomed. Eng., vol. 40, no. 7, pp. 640-653.

[2] Chintalacharuvu, R.R., D.A. Ksienski, and J.T. Mortimer, "A numerical analysis of the electric field generated by a nerve cuff electrode", Proc. 13th Ann. Conf. IEEE-EMBS 13(2):912-913, 1991.

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