A NEW INTRAMUSCULAR ELECTRODE FOR FUNCTIONAL ELECTRICAL STIMULATION IN THE RAT

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Abstract
In the recent decade Functional Electrical Stimulation (FES) therapy has been used successfully as an adjunct to traditional rehabilitation programs to improve the grasping and walking abilities of people with severe motor paralysis. The pathophysiologic effects of FES therapy are not known. This paper describes the fabrication of a new, low-cost, durable, and user friendly bipolar electrode that can be implanted into any extremity muscle in the rat for the purpose of administering FES therapy and recording EMGs. Female Long-Evans rats with an incomplete spinal cord injury (SCI) had an electrode implanted into each of their quadriceps muscles and hamstring muscles bilaterally for 7 days. The rats began receiving FES therapy 48 hours after implantation of the electrodes. No adverse soft tissue or behaviour changes were observed. This new implantable electrode facilitates the exploration of the pathophysiologic effects of FES therapy in rats with an incomplete SCI.

1 INTRODUCTION

FES therapy can restore the mobility and the reaching and grasping function of patients with an incomplete SCI and of patients who have had a stroke. The restored gross motor function in the upper and lower extremities is sustained following discontinuation of FES therapy for at least one year. FES therapy is not part of standard rehabilitation protocols. The neurophysiological effects of FES therapy are not known. Until now, the SCI models have been unable to biomechanically reproduce the most common type of SCI, flexion-distraction. In 2004, Dabney et al. published a new and reproducible computer-assisted flexion-distraction SCI model. This model replicates the biomechanical events responsible for most incomplete SCI.

To examine the effects of FES therapy in rats with a SCI, an implantable electrode was needed. Pearson et al. described a low-cost implantable bipolar electrode for the lower extremities of mice to record EMGs and movement. This electrode is difficult to fabricate and the externalized component of the electrode is not suitable for FES therapy. The bipolar electrode presented here was designed for administering FES therapy and for recording EMGs in rats. The idea for the internal component of the new electrode (major changes) originated from Pearson, while the Button/Tower component design is an unique design.

2 METHODS

2.1 Objectives
To describe the fabrication of a new implantable electrode to facilitate the exploration of the pathophysiologic effects of FES therapy in rats with an incomplete SCI.

2.2 Electrode Design

Intramuscular Electrode Component. The electrode was made using triple-stranded, Teflon coated annealed stainless wire with an outer diameter of 0.0060 inches (150 µm) (A-M Systems, Sequim, WA, USA) (Catalog Number 793400). A piece of wire measuring 30 cm in length was folded in half. A slip knot was used to attach the wire to a size 10 straight cutting Keith’s abdominal needle (Aspen Surgical, Caledonia, MI, USA)(Catalog Number 213410)(Figure 1A). Electrode orientation: the Keith needle is the proximal end of the electrode. A single knot was placed in the wire 6 cm distal to the end of the Keith needle.

Using a stereomicroscope and a #15 scalpel blade (Becton Dickson and Company, Franklin Lakes, NJ), 0.5 cm of Teflon was removed from one strand beginning 5 cm distal to the keith needle. Similarly, 0.5 cm of Teflon was removed from the opposite beginning and 4cm distal to the keith needle. (Figure 1B)

Peripheral Electrode Component (The Button). The Button consists of a Dacron mesh base and a "Tower" which houses an 8-pin connector. The internal component is connected to the Button through the 8-pin connector. The free wires at the distal end of

Figure 1: (A) Wire fastened to the size 10 Keith needle. (B) Knot (arrow) at 6 cm distal to Keith needle. Bared areas of wire (bold lines).
the electrodes were bared a short distance and prepared for soldering using Kester organic core SN63PB37 with Kester acid paste flux SP30. The prepared stripped wire tip was immediately soldered to one of the 8 pins of the female end of the 8 pin connector (Lemo-PLG.MO.8ZL.L) (Figure 2A). Eight wires were soldered sequentially to the appropriate pin of the 8 pin connector (Figure 2B). Devcon 5 minute epoxy gel was used to stabilize the connections (3B).

Figure 2: (A) Soldered wires to 8-pin connector. (B) Devcon epoxy gel stabilizing wire-pin connections. (C) Connector attached to Button.

The proximal end of each electrode was fed through the flexible tubing (0.105 inch lumen) of the Dacron Mesh Button Tether ("the Base") (Instech Laboratories, Inc. Plymouth Meeting PA, USA) as shown in Figure 2C and 3A.

Devcon 5 minute epoxy gel (ITW Devcon, Danvers, MA) was injected into "the Tower" from the distal end to stabilize the wire-pin connection within the tubing (Figure 3A). A small drop of epoxy gel was placed on the underside of the Base to adhere and stabilize the wires to the Dacron Mesh as they exit from the Tower (Figure 3B). The Tower was shrink wrapped to waterproof and stabilize the connection (Figure 3C).

Interface Cable. This cable connects the Compex Motion system to the Tower.

Tower Connection. A #15 scalpel blade was used to bare 0.5 cm of wire from each end of a 30 cm piece of seven-stranded Teflon coated annealed stainless wire with an outer diameter of 0.0090 inches (230 µm) (A-M Systems, Sequim, WA, USA) (Catalog Number 793500). The area was cleaned and prepared for soldering using Kester organic core SN63PB37 with Kester acid paste flux SP30. The tip was immediately soldered to one of the male ends of the 8 pins connector. A total of eight wires were soldered as described above and labelled (Figure 4, white arrow). A piece of dental floss, slightly shorter than the wires was attached to the male connector. The dental floss protected the wires from stretch. The underside of the connector was covered with epoxy gel to stabilize the pinwire connections. Once dry, the wires and the dental floss were all brought together and placed into a soft pipe (Figure 4, x).

Compex Motion Connection. The free, stripped end of the wires were cleaned, prepared for soldering using Kester organic core SN63PB37 with Kester acid paste flux SP30. The wire tips were soldered to Compex Motion connectors (figure 4, circle). The free end of the dental floss was attached to the wires when the connections were stabilized with epoxy glue. The connection was shrink wrapped (Figure 4, black arrow).

Figure 4: white arrow: Tower connection; x: pipe; circle: Compex Motion connectors; black arrow: shrink wrap

2.3 Computer-Assisted Flexion-Distraction SCI Model

Three female Long Evans rats (Charles River Laboratories, Inc., Wilmington, MA) with moderate flexion-distraction SCI as described by Dabney4 were used in all experiments. Perioperative care and monitoring were described by Dabney4. All animal care and use procedures conformed to those outlined by the Institutional Animal Care and Use Committee (IACUC), the American Association for the Advancement of Laboratory Animal Care and the US Department of Agriculture. Neurologic function was assessed using the modified 14-point Tarlov scale to establish the presence of hindlimb dysfunction4.

2.4 Implantation of the Electrode

The laminectomy (SCI model) incision was extended proximally to the mid-point of the scapula and distally to the top of the gluteus maximus muscles. A second approach, straight lateral to the thigh, was used to expose the quadriceps and hamstring muscles. The Button was placed between the scapula and the mesh secured to the subcutaneous tissue in four locations using 2-0 vicryl sutures. The Keith needles were colour coded and the insertion sites predetermined (Figure 5A). Each electrode was passed subcutaneously to the appropriate muscle. The electrode wires were twisted from the knot proximally, toward the eye of the needle. The electrode was inserted perpendicular to the long axis of the muscle fibers at the neuromuscular junctions up to the knot. The electrode position was secured with a vicryl knot placed around the wire ONLY at its insertion site into the muscle (Figure 5B). The needle was removed and the two wire ends tied off at the exit from the muscle (Figure 5B). The electrode was tested. This procedure was repeated until electrodes were inserted into bilateral hamstrings and quadriceps muscles. The subcutaneous tissue was closed using 2-0 vicryl and staples were used to close the skin.
2.5 FES Therapy

Forty eight hours post-op, FES was applied to the quadriceps muscles and the hamstring muscles using the Compex Motion electric stimulator. The frequency was set to 40 mHz. The pulse width and the current (mAmps) were varied to determine the optimum setting to obtain full contraction of the muscles.

3 RESULTS

The Animals. The modified 14-point Tarlov scores were 4 for all rats post-op days 1 and 7. Neither the subcutaneous nor the implanted wires or the Button appeared to irritate the rats. All animals were killed on post-op day 7. There were no intra-operative or post-operative complications. No adverse reactions to the Teflon coated wire were observed in the subcutaneous tissue or in the muscles. All of the wires were intact.

FES Therapy. Forty eight hours post-op, FES therapy was applied to the quadriceps and hamstring muscles. The pulse width (current) was increased in steps of 25 from 25 to 100. The current (mAmps) required to obtain a full contraction of the muscle was recorded for each pulse width. Each muscle was tested three times. The average score is plotted in Figure 6. The animals were in no pain.

4 DISCUSSION

The Electrode. It was inexpensive and easy to make. The following are the design highlights.

1. A simple slip knot was used to secure the wire to the Keith needle.
2. A straight Keith needle, designed to pass suturesatraumatically through soft tissue, was used.

3. The Dacron mesh base (Button) was designed to be implanted into rats. Initially it is stabilized with sutures. By 7 to 10 days tissue ingrowth into the Dacron mesh stabilizes the base.
4. The electrode is versatile. An 8-pin connector was used here. The number of pins in the connector can be changed as required.
5. Similar to reports by Pearson and Leblond, the presence of the wires in the subcutaneous tissue and in the muscles did not appear to alter the behaviour of the rats.
6. The design of the Button/Tower and the interface cable simplified the connection to the Compex Motion electric stimulator. The connection was very secure and no accidental disconnections occurred despite the increased mobility observed in the rats during treatment sessions.

5 CONCLUSIONS

The new implantable FES electrode described here is simple to make and to implant and does not appear to interfere with the behaviour of the rat. This electrode will facilitate the exploration of the pathophysiologic effects of FES therapy in rats with an incomplete SCI.

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7 REFERENCES


