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Hand Construction of Quadrifilar Wire Electrodes for Electromyography

Omar I. Ahmed, BS and Rick M. Roark, PhD

Department of Otolaryngology, New York Medical College, Valhalla, NY and The New York Eye & Ear Infirmary, New York City, NY

Abstract

Array electrodes have become increasingly popular for making surface and indwelling electromyographic (EMG) recordings. We describe a method for in-house construction of indwelling quadrifilar fine-wire electrodes. Quadrifilar electrodes facilitate the mapping of vector myoelectric signatures of motoneuron firing activities of the motor nucleus, a procedure referred to as EMG decomposition. The finished electrode has four detectors, each 50 μm in diameter, arranged in a rhombus pattern. Motor unit recruitment and firing information are aids to better understanding control deficits and behaviors evidenced in the final common pathway of the central nervous system.

Keywords

quadrifilar; array electrode; electromyography; hooked-wire electrode; decomposition

Introduction

Hooked-wire electrodes for electromyographic (EMG) recordings were first used by Basmajian & Stecko.² De Luca first demonstrated that quadrifilar (QF) needle electrodes could be hand constructed from hypodermic stock and used to obtain time series of multiple motoneuron firing activities. They were used for a pattern recognition technique that has become commonly referred to as “EMG decomposition.”^{1,4} A QF electrode, whether needle or hooked-wire variety, contains four detecting surfaces 50 to 75 μm in diameter that are configured in a square or rhombus pattern spaced 100 to 200 μm apart. Given that human muscle fibers are typically in the range of $53 \pm 16 \mu\text{m}$, the QF electrode insures that myoelectric recordings span more than a single fiber. They can selectively record depolarization activities of multiple muscle fibers in the volume of muscle surrounding the indwelling electrode.^{1,6} The four detectors are routed to multi-channel EMG amplifiers to obtain a vector of bipolar EMG recordings as illustrated in Figure 1A. Because of the square-like pattern, each bipolar pair provides a distinct perspective of the depolarization potentials from each motor unit. Given a different pairing of detectors, and/or a different electrode position, the pattern signatures associated with each motor unit will change; however, the set of signals—when taken together—remains distinct. It has been determined by empirical tests that a square-like pattern provides the greatest signal separation between motor units, as compared to other possible configurations (such as all detectors in a straight line).³ Coincident firings of multiple motor units when they occur may be resolved by a superposition resolution technique.

QF wire electrodes are further discussed in De Luca & Adam³ and by other authors, but sparse details have been provided about their actual construction. QF wire electrodes must be manufactured in-house, since they are not yet available commercially. A consistent method of constructing QF wire electrodes will enhance uniformity of EMG recording techniques and provide coherence to the interpretation of results among various laboratories. With the advent of open-licensed EMG decomposition routines, QF recordings are becoming increasingly popular.^{5, 8}

Materials and Methods

A variety of wire stock is commercially available that satisfies the conductance, tensile strength, and safety requirements for EMG wire electrodes. Stainless steel or nickel-chromium wire .002" in diameter with .0005" thick nylon coating has proven efficacious for experiments in our laboratory (California Fine Wire Co., Grover Beach, CA). Four wires 40 cm in length are fed through a hypodermic needle. The wires should be inserted via the hub of the needle (proximal end) to reduce the possibility of insulation scarring by the beveled insertion tip of the needle (distal end). Typically, 25 or 26 gauge needles are used. Needle cannula length is selected according to the required depth of electrode insertion, typically 20 to 50 mm.

Wires at each end are loosely bundled together and temporarily secured with adhesive tape. Smooth nylon-jawed jeweler's pliers (Shor International Corporation, Mt. Vernon, NY) are used to grasp the four conductors approximately 50 mm from the taped distal end. Hand twisting the taped bundle about ten rotations will force the four wires into a rhombus pattern that approximates the target square configuration as shown in Figure 1C. A miniscule droplet of surgical-quality adhesive (2-octyl-cyanoacrylate) placed 5 mm from the distal end of the twisted bundle will secure the arrangement, while allowing the remaining portions of the wires to float freely within the needle shaft.

With the aid of a zoom optical microscope (power ~ 20-50), a cut of the twisted wire bundle is made using a single-use, single-edge razor blade or similar sharp instrument. The desired configuration is best maintained if the wire bundle is cut in a single fluid movement. As denoted in Figure 1C, a cut at location 'Y' will provide a more compact electrode array than when a cut is made at location 'X' just beyond the adhesive margin, which permits a small separation of the four wires. Slightly greater separation is sometimes desired when using the electrode in muscles with larger diameters.

Approximately 2 mm of the distal bundle is bent to at least a 90° angle using the smooth-jawed pliers. This angle is sufficient to anchor the wire electrode into the muscle once the needle is withdrawn. The electrode array is examined under the microscope to insure that the desired configuration has been preserved and that four bare detector surfaces have been created by the cutting process, as illustrated in Figure 1D. Approximately 1 cm of insulation at the proximal end of the four wires may be removed by the flame of a small ethanol lamp for bare connection to the EMG amplifier interface. A volt-ohm meter successively tests for unintentional short-circuits that may have been created at the distal end during the construction process. Sterilization of the wire electrodes should adhere to the approved procedures of the sponsoring institution (e.g., gas, boiling, chemical, or steam).

Results & Discussion

Wire electrodes find greatest utility in EMG studies that involve dynamic muscle contractions, prolonged recordings, and when patient comfort is a concern. There is typically

less migration of a hooked-wire electrode within muscle compared to a needle electrode, which is critical for EMG decomposition. A noteworthy disadvantage to hooked-wire electrodes, however, is their inability to be relocated once they are placed. The wire electrode provides for bipolar detection of micro-MUAPs (motor unit action potentials), as illustrated in Figure 1A for Channels 1 to 3, and a monopolar macro-MUAP signal that is detected by Channel 4.1 Alternatively, four bipolar connections can be made. An isolation buffer amplifier (not shown) is used before passing wire signals to the EMG amplifier array.

The QF electrode and amplifiers provide a vector of EMG signals to decomposition algorithms, which greatly strengthens the ability to discern and track individual motor units as compared to single-channel bipolar recordings. As noted at the location of the arrows in Figure 1B, MUAP identification and tracking would not be reliable if it were based solely upon the bipolar recording of Channel 2, given that the myoelectric signatures of MU₁ and MU₂ are substantially similar from the perspective of this detector pair. When the signatures provided by all channels are combined, however, correct identification is achieved.

An idealized vector configuration has been created by the electrode-amplifier connections in Figure 1A, as indicated by the red arrows; however the actual vectors may be unknown. For some experiments, our laboratory employs a matrix pinboard (Info-Lite Corporation, Indianapolis, IA) to interface buffered wire signals to EMG amplifiers, as depicted in Figure 1A. Prior to EMG recording, pins are arranged by trial-and-error to maximize signal differences between the three bipolar channels, under the assumption that decomposition will be facilitated. In other experiments, we do not concern ourselves with connection specifics, and we typically achieve similar decomposition outcomes. We believe that our ability to achieve reliable decompositions in this latter case is due to the fact that we insure the square-like pattern of the wire electrode versus the results that would be obtained by a random-pattern electrode.

Using this protocol, QF wire electrodes have been employed in multiple research studies conducted by our laboratories at New York Medical College and the New York Eye and Ear Infirmary.⁹ Together with other investigators, we have demonstrated the reliability and reproducibility of the technique.³ We are currently using these electrodes in laryngeal muscles to study focal dystonia (NIH 5 R21 DC008786). Figure 1B shows sample data collected using the QF wire electrode. The subject was a 28 year-old woman who, following IRB-approved consent, underwent percutaneous insertion of the QF wire electrode via the superior thyroid notch at midline, and it was then positioned laterally into the right thyroarytenoid muscle. Data were collected from the thyroarytenoid muscle during a raster of vocal exercises for analysis using decomposition algorithms.

Though to date there are only a handful of citations that report data collected from QF hooked-wire electrodes, their use has been recently increasing. QF electrodes and decomposition techniques may have particular importance for studies of clinical conditions such as muscle dystonia, Parkinson disease, and lower motor neuron disease – areas that remain largely unexplored by this approach. By providing the perspective offered by motoneuron recruitment and firing characteristics, the QF wire electrode in combination with EMG analysis routines will provide researchers the opportunity to gain greater insight into neuromotor diseases via physiologic signals obtained in the periphery.⁷

Acknowledgments

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Abbreviations

EMG	electromyographic
QF	Quadrifilar
MU	motor unit
MUAP	motor unit action potential

Figure 1.

(a) Schematic of the QF wire electrode and a possible connection scheme to the EMG amplifier array. Each wire channel is isolated by a buffer amplifier (not shown) before connecting to the EMG amplifier array. (b) Sample vector EMG signals obtained from the QF wire electrode showing three motor units with distinct signals. (c) The twisted wire bundle, held together with surgical adhesive. A cut at location “Y” provides a tighter detector configuration than a cut at location “X” located beyond the adhesive margin. (d) Microscope view of the finished QF hooked-wire electrode and insertion needle.