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A multiwire microelectrode for single unit recording in deep brain structures

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A method is described by which a single shaft multiwire microelectrode can be fabricated efficiently The resulting electrode can be attached to a commercial microdrive and used for single neuronal unit recording from one or more tracks in deep brain structures of anesthetized or awake animals. The electrode consists of a 30 gauge stainless steel cannula through which multiple strands of 13 μm insulated tungsten microwires are threaded At the electrode tip the wires protude 3–4 mm from the cannula and are cut individually at suitable offsets. The tip is stabilized and fixed to the cannula with cyanoacrylate At the base of the electrode the wires are threaded through flexible plastic tubing that provides strain relief and are glued to individual pins of a miniature connector that plugs into a field effect transistor (FET) voltage follower. Good single unit recordings have been obtained routinely from the basal ganglia of awake, behaving monkeys with this electrode

Introduction

Multiple channel single unit recording is an attractive alternative to single channel recording because more data can be obtained for each recording site (Eichenbaum and Kuperstein, 1986). This is particularly advantageous when data are obtained from a trained behaving animal since the number of trials an animal will perform is limited. A second advantage of multiple channel recording is that simultaneously recorded single units can be analyzed for functional interactions, for example, by constructing cross-correlograms (Perkel et al., 1967). This type of analysis allows a first step towards describing the network level of neuronal functioning, which is essential to information processing by the brain.

In many single unit studies, recordings are obtained in daily penetrations so that over time a grid of tracks is formed to sample units from a structure. Most current multiple channel microelectrodes, however, can be implanted in one position only (Chorover and DeLuca, 1972, Eichenbaum et al., 1972; Palmer, 1978) or allow recording of a single track (Kubie, 1984; Diana et al., 1987). Michalski et al. (1983) obtained multiple cortical penetrations with a bundle of 12 μm tungsten microwires glued into a glass pipette. Some investigators have implanted arrays of microelectrodes (Krüger and Bach, 1981; Krüger, 1982) to sample multiple single units from a structure. This approach has been used for recording sites that are close to the brain surface. Current designs of printed circuit multiple channel elec-

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trodes are also suitable for superficial recordings only (Eichenbaum and Kuperstein, 1986). We have developed a method to fabricate multiple channel microelectrodes that are well suited for multiple penetrations to record from deep structures. We have used this electrode routinely for over a year to record from the basal ganglia of awake, behaving monkeys (Jaeger et al., 1988).

Materials and method

The overall structure of the electrode is shown and described in Figs. 1 and 2. A scanning electron micrograph of the electrode tip structure is shown in Fig. 3. With practice, an electrode can be manufactured in 90 min. Each electrode can be used for multiple penetrations.

Fig. 1. Photograph of a multiwire microelectrode attached to a Kopf microdrive. The shaft of the electrode is clamped at the top. The lower portion of the shaft slides through a 23 gauge hypodermic needle that is used to penetrate dura and acts as a guiding cannula as well. It is fixed at a position such that it will not penetrate beyond superficial cortical layers. At the upper end of the electrode a microconnector plugs directly into an FET voltage follower. A flexible piece of plastic tubing between the base and the electrode shaft allows advancement of the electrode while the connector is firmly attached to the microdrive

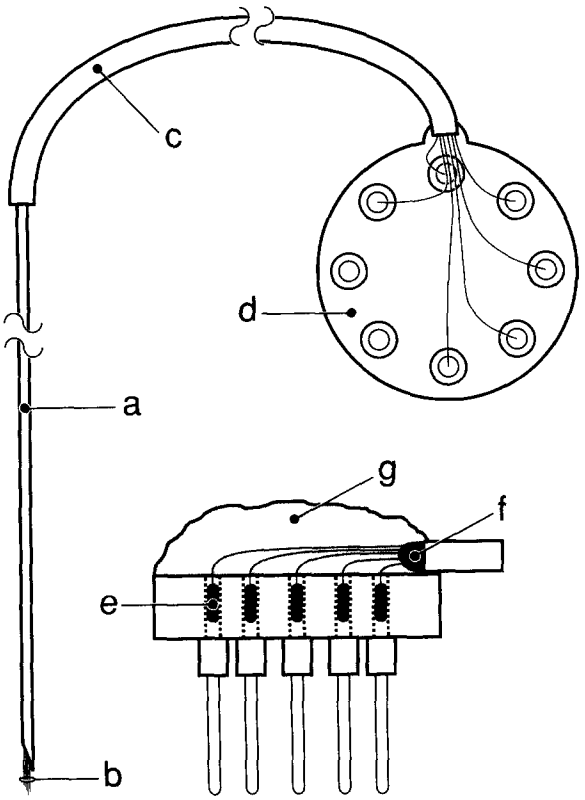

Fig. 2. Schematic drawing of the multiwire electrode The multiwire electrode consists of 4–10 strands of HM-L coated 13 μm microwires (b) that are threaded through a 30 gauge stainless steel cannula (a) The tungsten wires protrude from the bevel of the cannula for 2 5–4 mm and each wire tip is arranged at an offset of 50–200 μm from the other tips On the base of the electrode each wire is connected to a single pin hole of an Augat transistor microsocket (d), which serves as a connector to a FET voltage follower Between the base of the electrode shaft and the connector all wires are guided through a length of flexible plastic tubing (c) The inset shows another view of the connector The shaded area indicates the protective epoxy cover (g) The wires are connected using silver-based epoxy (e) The entrance of the wires to the flexible tubing is blocked with vaseline (f) to prevent epoxy from entering the tubing.

To begin electrode construction, a shaft is prepared by cutting 30 gauge stainless steel tubing (Small Parts, Inc.) to the desired length and bevelling it on one side with an abrasive disk mounted on a dremel tool. The cannula ends are then cleaned of burrs with a #00 insect pin mounted on a pin chuck. A steel wire is threaded through the cannula to check for obstructions and to smooth the insides of the cannula ends. Air is blown through the cannula to clear it of any metal particles that have collected inside. A bundle of microwires can then be threaded through the prepared cannula. Four to 10 strands of 13 μm (0.0005 in) HM-L coated microwire (California Fine Wire Company) of the desired tip to connector length with 10 cm added are cut. To simplify threading, all wire strands are glued together at one end with penetrating superglue (Super Bonder 420, Loctite Corporation). The glued bundle is then threaded through the 30 gauge cannula from base to bevel by hand. This is best done at 40 × magnification with the aid of a binocular microscope. During threading the cannula is held by an alligator clip mounted to a suitable stand. The tungsten wires should not be held with metal forceps as this can cause the HM-L coating to break. After the tungsten wires are threaded through the cannula, the glued part is cut off. The separated wire tips are then extended to approximately 10 mm beyond the cannula bevel and cut individually at desired offsets with fine, sharp scissors. The whole bundle of tips is then pulled back so that tips protrude between 2.5 and 4.0 mm from the cannula bevel. At the tip base, a drop of penetrating superglue is then applied with a wooden applicator to fix the wire positions and stabilize the tip. If the wire ends are splayed apart or curve excessively, the tip can be redone by unbonding it with acetone, realigning the wire ends and gluing them back together. Unbonding and realigning the tips is best done with a pair of cotton tipped applicators at 25 × magnification. To complete the electrode the bundle of microwires emerging at the base of the cannula is threaded through a piece of protective plastic tubing and the wire ends are glued to individual pinholes of an 8-pin Augat transistor socket. To do this the plastic tubing is first glued to the transistor socket with superglue. The tubing should have an inner diameter just large enough to slide over the end of the 30 gauge shaft of the electrode. The wire bundle is threaded through the plastic tubing with the attached Augat socket. The wire ends are again glued together before threading. A drop of mineral oil is then applied to the junction of 30 gauge cannula, tungsten wires and plastic tubing before the end

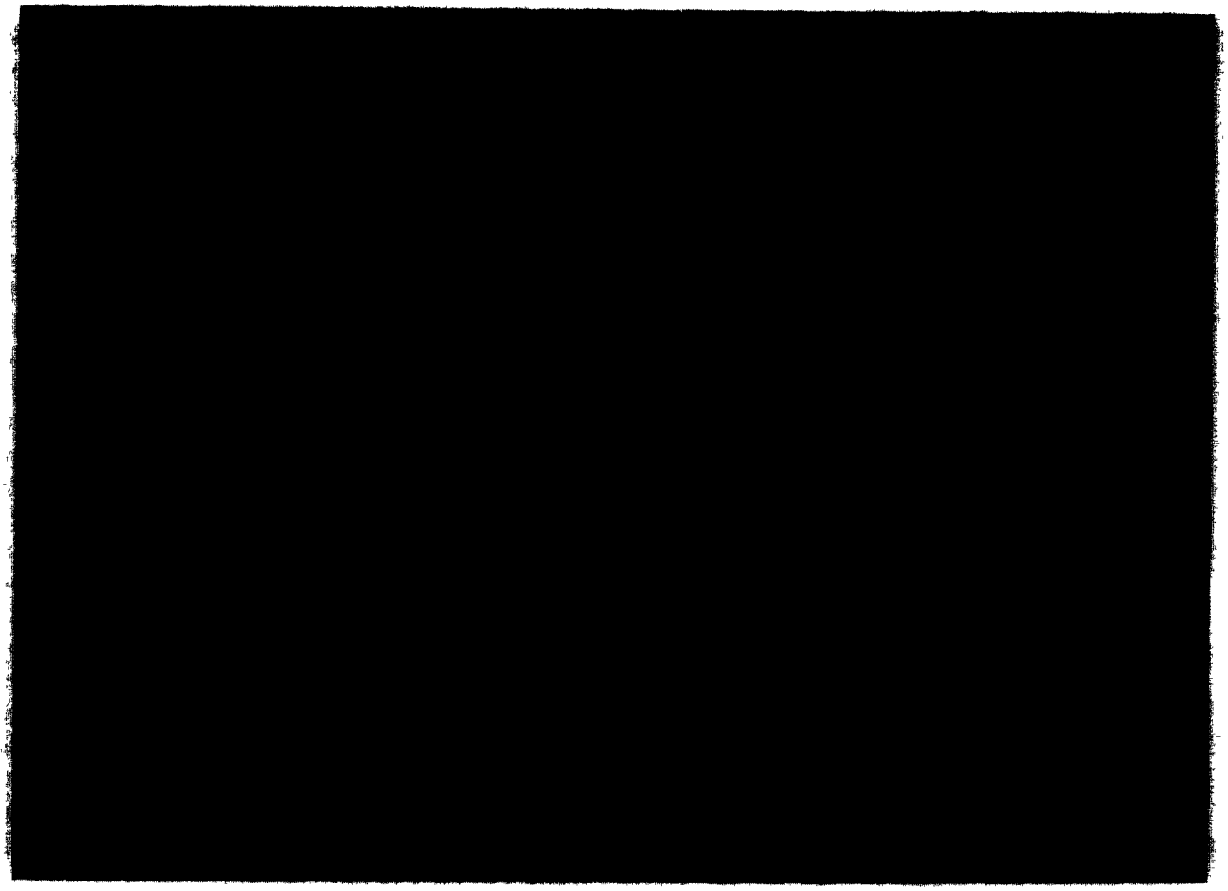

Fig. 3 Scanning electron micrograph of the electrode tip The tungsten microwire ends are glued together with penetrating superglue to avoid bending and divergence of individual wires while the electrode is advanced into the brain Note that the superglue does not cover the recording tips of the tungsten wire

of the tubing is slid over the base of the 30 gauge cannula. The oil is sucked into the plastic tubing by capillary action. Applying oil to the wire bundle in this way greatly reduces recording artifacts due to the friction of tungsten microwires sliding against each other inside the cannula and plastic tubing. This is particularly important when recordings are taken from moving animals. The HM-L insulation is stripped off the ends of the tungsten wires with two pairs of watchmaker forceps at 12–16 × magnification. The exposed tungsten wire ends are each glued into one pin hole of the connector with conductive silver epoxy. As the last step, 5 min epoxy is used to cover the entire back side of the connector to protect the tungsten wire ends during electrode handling. To avoid breakage of the wire bundle inside the flexible tubing, care must be taken that no epoxy enters the end of the plastic tubing, which is best blocked with vaseline or grease.

The electrode is now ready to be attached to a microdrive. We have used a Kopf hydraulic microdrive (model 1207B) for this purpose. The impedances of individual wires should be tested, and in our experience acceptable impedances, tested at 1000 Hz, range from 600 KΩ to 1.5 MΩ. In addition, a DC current from a 9 V source with a 1 MΩ in series resistor can be passed through the wires with the wire tip as the negative pole to produce at the wire tips bubbles that can be

observed through the binocular microscope. This test is instrumental in matching each electrode wire tip to each pin on the Augat socket.

Results and discussion

We have used microelectrodes with six 13-μm tungsten wires for recording unit activity from the basal ganglia of behaving monkeys for over a year. Recording artifacts due to animal movement were successfully eliminated by applying mineral oil to the microwires inside the electrode shaft and plastic tubing. With this method, artifact free recordings could be obtained even though the animals were allowed free head movements. At each recording site we choose 4 of the 6 electrode wires for data collection. The quality of unit isolation (Fig. 4) and the ability to hold single units was similar to conventional tungsten microelectrodes (Micro Probe, Inc., WE500315A), which we have used in earlier studies with awake monkeys.

In addition to 13 μm HM-L coated tungsten wires, we have tested multiwire electrodes with 25 μm HM-L coated tungsten wires and 25 μm HM-L coated stainless steel wires. Single unit isolation was less satisfactory than for 13 μm tungsten wires in both cases. Diana et al. (1987) report better unit separation with multiwire electrodes when they use 18 μm steel wires as compared with 25 μm steel wires, which is in agreement with our result that smaller diameter wires are better suited for single unit recording. Diana et al (1987) also note that for steel wires better unit isolation is obtained when the wire is double coated with Parylene and HM-L.

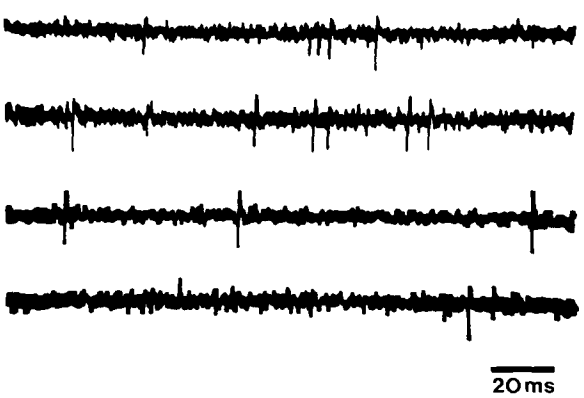

Fig. 4 Four simultaneous recording traces from the putamen of a behaving monkey These traces were recorded from a multiwire microelectrode with 13 μm tungsten wires A unit can be discriminated on each channel. The first trace shows two differently sized spikes that can be discriminated as 2 single units

Kaltenbach and Gerstein (1986) report a method of sharpening the tips of flush cut 25 μm HM-L coated tungsten wires. Sharpened electrodes result in better single unit isolation in their experience. Sharpened 25 μm tungsten wire electrodes were reported to have impedances from 300 KΩ to 1.5 MΩ, which is similar to our impedances for unsharpened 13 μm tungsten wires Improvement in unit separation from sharpening 13 μm wires would probably be less than for 25 μm wires because flush cut 13 μm wires have finer tips than 25 μm wires even before sharpening

Eichenbaum and Kuperstein (1986) in their review on multichannel microelectrodes stress the advantage of printed circuit microelectrodes over bundled microwire designs. The former can be mass produced reliably while the latter need to be manufactured individually We agree with this judgment in principle, however, to our knowledge there are no microcircuit electrodes available that allow recording from deep structures It is difficult to achieve this goal since long electrode shafts cannot be built from a silicon wafer and to our knowledge connecting wafer electrode tips to wires has not been achieved on a scale small enough to fit inside a steel cannula suitable for depth recordings. Thus, currently printed microcircuit electrodes seem to be best suited for cortical recordings

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