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Pasteless electrode for clinical use

C. J. De Luca R. S. Le Fever F. B. Stulen

Department of Orthopaedic Surgery, Children's Hospital Medical Center, Harvard Medical School, Boston, MA 02115, USA and Massachusetts Institute of Technology, Cambridge, MA, USA

Abstract—*The design and construction of a clinically useful electrode for detecting the myoelectric signal is described. The requirements of the design were determined by a set of properties defined by clinicians and research engineers experienced in myoelectric signal detection. A novel, and seemingly useful, feature of this electrode is that the stainless-steel cans of two junction field-effect transistors are used as the recording surface while the same j.f.e.t.s operate as the front end of a differential preamplifier. The electrode requires no paste or gel. In addition to its use as a stationary unit, it may be used as a probe to quickly and conveniently explore the myoelectric signals from many muscles.*

Keywords—*Electrodes, Myoelectric signals*

1 Introduction

THE recent revitalisation of interest in myoelectric biofeedback and electrophysiological kinesiology, accompanied by the current upsurge in the quantitative assessment of muscle re-education exercises, has produced a need for an easy to use and reliable electrode for detecting the e.m.g. or the myoelectric signal. Such an electrode would be convenient in a clinical environment.

In the past, various types of surface electrodes have been used to detect myoelectric signals. They can be conveniently grouped into three categories. The first category consists of a simple metal disc or plate in contact with the skin surface via a conductive paste or gel. Any metals with good conductivity may be used; the most common, however, are stainless steel and nickel. The lack of chemical equilibrium at the metal/electrolyte and electrolyte/skin junctions sets up a polarisation potential that may vary with temperature fluctuations, sweat accumulation, changes in the electrolyte concentration of the paste or gel, relative movement of the metal and skin, as well as the current flow. Various construction designs have been implemented in an attempt to stabilise the polarisation potential (BOTER *et al.*, 1966; GIRTON and KAMIYA, 1974).

The second category consists of the widely used silver/silver-chloride electrode, which also makes contact with the skin via a conductive paste or gel. This electrode has the advantage of having a reduced as well as more stable polarisation potential. Both of the above categories of electrodes work best if the skin is prepared by rubbing it with solvents to remove the oils and by treating it with abrasives to remove dead epidermis (SHACKEL, 1959; TAM and WEBSTER, 1977; BURBANK and WEBSTER, 1978). This procedure reduces the impedance of the skin/electrolyte interface.

A third category of electrodes has been employed to eliminate the need for skin preparation and conducting medium. These have been referred to as the dry electrodes. These electrodes can be either resistively coupled (LEWES, 1965; BERGEY *et al.*, 1971) or capacitively coupled to the skin (LOPEZ and RICHARDSON, 1969; POTTER and MENKE, 1970; BETTS and BROWN, 1976). In the case of the capacitively coupled electrode, the recording surface is coated with a thin layer of dielectric substance and the skin electrode junction behaves as a capacitor. Although the capacitively coupled electrodes have the advantage of not requiring a conductive medium, they have a higher inherent noise level (POTTER and MENKE, 1970). Also, these electrodes do not have a long term reliability because their dielectric properties are susceptible to change with the presence of perspiration and the erosion of the dielectric substance.

The design presented in this paper represents an improvement to the current forms of resistively coupled electrodes.

2 Electrode requirements

Inquiries made of clinicians and researchers experienced in the use of myoelectric-signal electrodes indicated that a suitable electrode unit (including its associated electronics) should have the following desirable properties:

Physical properties

(*a*) it should be easily and quickly affixed to and removed from the skin of an individual

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(*b*) it should not require a conductive paste or gel between the electrode surface and the skin
(*c*) it should be small in size, light in weight and ruggedly constructed
(*d*) it should not be cumbersome or obtrusive to either the subject or the clinician
(*e*) it should be inexpensive and easy to construct.

Electrical properties

(*a*) it should be a surface differential electrode whose associated electronics should have a common mode to differential conversion ratio of at least 5000 (74 dB) at 60 Hz
(*b*) it should have an actual input impedance of at least $10^8\ \Omega$ at 100 Hz: note that the input resistance will always be shunted by some inherent or stray capacitance, which will reduce the actual impedance
(*c*) the d.c. input bias current should be kept at a minimum, thereby reducing the polarisation potential
(*d*) the a.c. output impedance should be sufficiently low (less than 2 kΩ) to reduce any signal attenuation, common mode inbalance caused by the output-cable capacitance, 60 Hz inductive pickup and motion artifacts generated in the output cable
(*e*) it should not restrict the bandwidth of the myoelectric-signal processor
(*f*) it should be electrically stable so as not to have time dependent effects on the characteristics of the detected myoelectric signal
(*g*) it should have a thermal noise less than 2 μV r.m.s. over the bandwidth of the recorded myoelectric signal (higher noise levels reduce the effectiveness of the electrode in detecting signals from weak muscles)
(*h*) it should have a stable, reliable and judiciously located ground reference contact. The location of the ground contacts with respect to the recording contacts must be a compromise: the distance should be sufficiently small to minimise the size of the electrode unit, but sufficiently large so that the recording contacts do not short to ground when the skin perspires
(*i*) it should have a low current drain.

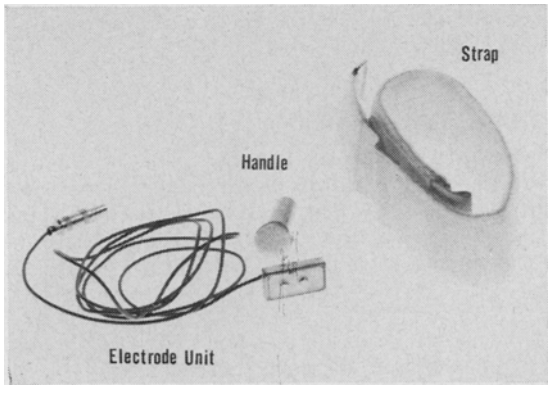

Fig. 1 Electrode unit, handle and strap

3 Design and construction

The above requirements can be achieved by a suitably designed resistively-coupled dry electrode consisting of a pair of unity-gain buffer preamplifiers located very close to the recording surfaces. This is a well known strategy that has been used for the past decade (LOPEZ and RICHARDSON, 1969).

After attempting several configurations, the following design emerged. The electrode unit consists of four basic components: the metal shell, which performs a dual function as a housing for the electrode and as the ground contact; the attachments, consisting of a strap and a handle; the recording contacts and the cable. The complete unit is presented in Fig. 1.

The shell consists of a milled block of highly pure (99·71%) titanium metal (ASTM No. 8348). The external measurements are 30 mm long, 15 mm wide and 7 mm deep. Metal is removed from the interior of the block by milling, forming a rectangular shell having a wall thickness of 2 mm. Titanium metal of high purity is used because it is highly resistant to oxidation, has outstanding corrosion resistance, can be milled with relative ease and is relatively inexpensive. However, any corrosive-resistant conductive metal can be used. The rectangular border of the shell acts as the ground contact and the remainder of the shell forms a shield against the inevitable ambient electromagnetic radiation. A hooked Velcro strap cemented to the back of the shell mates with the attachments that support the electrode.

The recording surfaces are formed by the cans of the two junction field-effect transistors (j.f.e.t.s), which have a diameter of 4·5 mm. Their cans, made of stainless steel, are polished. The j.f.e.t.s (2N4220A) are used as both the recording surfaces and the front end of the two buffer preamplifiers. The two j.f.e.t.s are cemented with epoxy glue in the middle of the shell. Their centres are spaced 10 mm apart. This spacing allows the electrode unit to be as small as possible while maintaining sufficient separation so that the recording surfaces will not short when the skin perspires. The tops of the cans protrude 1 mm above the surface of the border of the electrode shell. This protrusion is essential to insure that the recording surfaces will always touch the skin. The weight of the electrode unit, excluding the cable, is 5·2g.

The lead from each of the j.f.e.t. cans (pin 4) is soldered to its corresponding gate lead (pin 3). This arrangement reduces the stray capacitance in the front end, which in turn increases the actual

input impedance. The j.f.e.t.s act as unity gain buffers in a constant-current source follower arrangement, shown schematically in Fig. 2. The drain leads (pins 1) of the f.e.t.s, are tied together and supplied with a positive voltage (typically +4·5V) through for the j.f.e.t. sources and set the bias current through the j.f.e.t.s (typically 100 μA).

With this arrangement, instrumentation amplifiers with relatively large d.c. input bias currents (<100 μA) may be used, such as an Analog Devices

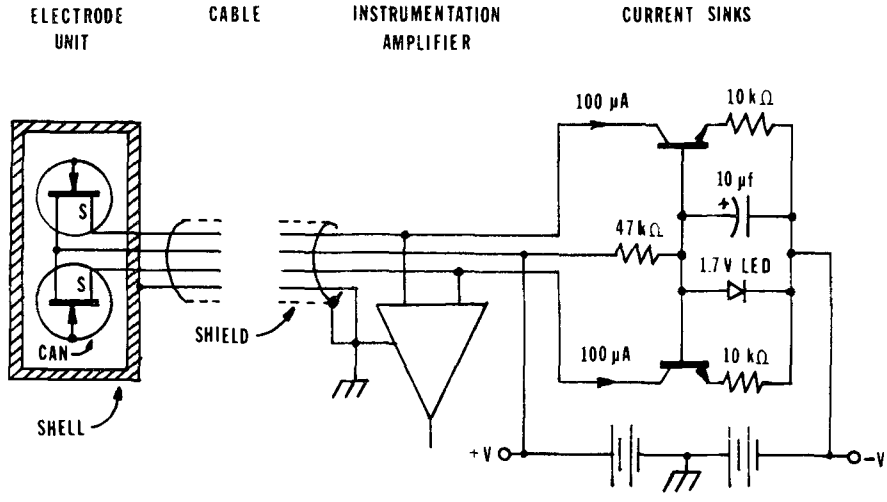

Fig. 2 Schematic of electrode unit and supplementary circuitry

one lead in a four conductor shielded cable. The cable shield and another conductor connect the circuit ground (common) to the titanium shell of the electrode to provide the ground reference. The source leads (pins 2) of the j.f.e.t.s are connected through the two other leads in the shielded cable to the differential inputs of an instrumentation amplifier. This amplifier should have a high a.c. input impedance (>100 MΩ). The two *n–p–n* transistors located next to this amplifier act as constant current sinks 521. The instrumentation amplifier provides all of the common mode rejection, anplification and bandwidth limitation of the electrode unit. The instrumentation amplifier and its associated electronics, as well as the current sink circuit, are physically separated from the electrode unit by the cable, hence, they can conveniently reside in the device to which the electrode is attached. This arrangement reduces the cost of the electrode unit when it becomes necessary to replace it.

The described configuration of each buffer preamplifier of the electrode unit has the typical performance characteristics shown in Table 1.

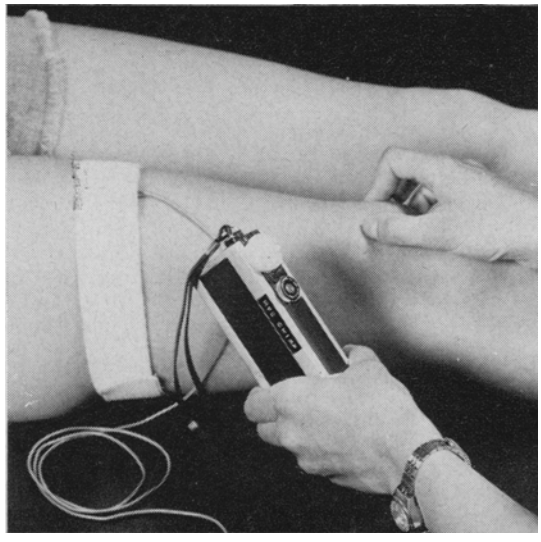

Fig. 3 Electrode unit secured to limb with strap implement

Table 1. Typical performance characteristics

Bandwidth	d.c. to >100 kHz
D.C. input bias current	<100 pA
A.C. input impedance	$>10^{10}\,\Omega$ paralleled by 5 pF
A.C. output impedance	1·6 kΩ
Noise (differential) inputs grounded	<0·04 μV r.m.s./$\sqrt{}$Hz
each input with 10 kΩ to ground	<0·05 μV r.m.s./$\sqrt{}$Hz (<0·7 μV r.m.s. for 200 Hz bandwidth)
Common mode to differential conversion ratio (similar to c.m.r.r.)	>75 dB at 60 Hz (driving 500 pF to ground of cable capacitance)
Power supply drain	~350 μA at ±4·5 V

Two devices for affixing the electrode to the skin have been developed: one is a strap and the other is

a handle. The strap consists of two strips of Velcro pile sewn back to back with a piece of elastic nylon webbing sewn to each end. The free end of one of the elastic strips is attached to two small strips of Velcro hooks that are sewn back to back. The end of the other elastic strip is sewn to a loop of Velcro pile that loops through a D ring. This arrangement allows the strip to encircle body segments of varying perimeters. The handle consists of a plastic rod with a Velcro patch cemented to one end. This also mates with the Velcro patch on the back of the electrode shell. These implements can be seen in Fig. 1.

When the electrode unit is to be stationed over a particular muscle, the unit is affixed to the Velcro pile on the strap via mating Velcro hooks, and the strap is wrapped around a body segment. Typically, the electrode unit is positioned over a limb muscle, as shown in Fig. 3. However, with a longer strap the electrode unit can be attached to the thorax. The strap arrangement assures that the electrode unit is anchored with sufficient pressure to make a stable contact with the skin. The elastic strips in the strap allow it to expand when the muscle is contracted, thereby eliminating the uncomfortable pressure sensation and restricted blood flow that would otherwise be experienced by the subject. No paste or gel is required. If the skin making contact with the electrode unit is clean, the electrode assembly will become electrically stable within 5 to 10 s. Otherwise, the unit should be removed and the skin should be swabbed with rubbing alcohol, which should be allowed to evaporate prior to re-attaching the electrode unit.

Alternately, the electrode unit may be used as a probe by attaching the handle to it. In this configuration the electrode unit is simply held, with some pressure, against the skin over the muscle of interest, as shown in Fig. 4. To guarantee consistent and reliable performance, it is preferable to rub the electrode face on the skin area on which it is to be located.

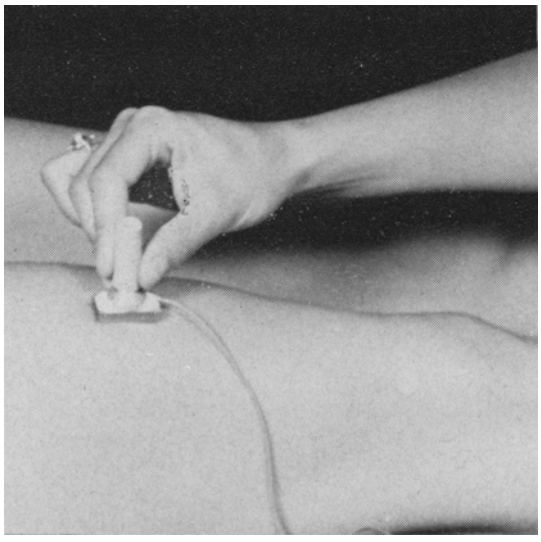

Fig. 4 Electrode unit employed with a handle as a probe for exploring myoelectric activity

The electrode unit may serve as the front end for most apparatus used for recording the myoelectric signal. Currently, the electrode unit is used with a myofeedback device constructed in our laboratory (see Fig. 3). The myofeedback devices have been used on a regular basis by physical therapists. The convenience and effective performance of the electrode unit were well received in a busy, clinical environment. They found the probe feature and freedom from the need for a paste or gel particularly convenient. No problems with the electrode unit were reported during eight months of daily use in clinics.

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