ELECTRODES FOR CLINICAL MEASUREMENT OF BIO-ELECTRIC POTENTIALS : IMPEDANCE AND SPATIAL SELECTIVITY

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ABSTRACT

The rapid increase in use of physiological measuring and myo-electric control equipment has led to renewed interest in certain properties of measuring electrodes. In gait studies and multi-channel myo-electric control applications the spatial selectivity of electrodes assumes prime importance. Development of surgically-implanted myo-telemetry control systems, and use of single motor units or small segments of muscle as control sites makes this topic even more critical. In all measurements, but particularly in myo-electric control, achievement of stable electrode-to-tissue interface impedance is a prerequisite for reliability.

In this paper, the results of a series of surface electrode measurements are presented, indicating the effects of electrode design, skin preparation and choice of electrode paste upon magnitude and variation of electrode-to-tissue impedance. The balance of the paper is devoted to a discussion of spatial selectivity of electrodes. Experimental data concerning crosstalk measurements on multi-channel myo-electric control systems are presented. Electrode design for specific selectivity is discussed, with examples of special-purpose electrodes developed in the research programme of this Institute.

SURFACE ELECTRODE EVALUATION

The impedance between a surface electrode and the living tissue from which a bio-electric potential is to be measured is of considerable importance. This electrode-to-tissue interface impedance, hereafter referred to simply as the electrode impedance, acts with the amplifier input impedance to cause attenuation of the signal. More important, differences between electrode impedances can cause serious degradation of the common-mode rejection performance of a differential amplifier. An electrode evaluation study was carried out recently to provide electrode impedance data which could be used for instrumentation design and as an aid in choosing electrode, electrode paste and skin preparation techniques for specific applications, [1].

38 combinations of commercially-available surface electrodes and electrode pastes, and skin preparation techniques, were assessed. In each case data were measured for at least 10 subjects, mixed male and female university students. Electrodes were spaced 1.25" on centres over the trapezius muscle. Impedance measurements, at 60 and 400 Hz, were performed using a Technology Instrument Corporation Type 310-A Z-Angle Meter, with an applied potential of 40 mv. The mean impedance (magnitude) and range were tabulated for measurements 5 and 30 minutes after electrode application.

From these data certain general conclusions follow. It is reasonable to expect an electrode impedance of 5 kilohms at 400 Hz and 10 kilohms at 60 Hz given appropriate attention to skin preparation and electrode paste selection. In all measurements, the standard deviation is roughly one third of the mean impedance. In choosing an electrode paste, bulk resistivity is relatively unimportant; the ability to penetrate the epidermis is much more important. As anticipated, electrode impedance may be reduced by increasing electrode area, or by more effective skin preparation. Application of electrodes of any type over unprepared skin leads to high and erratic impedances, which stabilize somewhat in a period of 30 minutes. Rubbing the skin briefly with electrode paste is a satisfactory method of skin preparation. The paste need not contain an abrasive.

SPATIAL SELECTIVITY

In most applications other than

electrocardiography, knowledge of the spatial selectivity of the electrodes used is important. In multi-channel myoelectric control systems it is essential. The problem of crosstalk among closely-spaced control sites leads to a demand for electrodes which are highly selective. At the same time, the desire to utilize some degree of spatial averaging to minimize the influence of local anomalies leads to a demand for low selectivity. Again, with percutaneous or totally implanted systems, the desire to minimize trauma leads to a demand for very small (hence highly selective) electrodes, while the requirement of mechanical durability dictates that the electrodes be relatively large (and unselective).

We have no solution to these problems, but can describe some experimental work which may stimulate others to contribute to their solution. It may be that a thorough theoretical analysis will prove helpful. There is an excellent and comprehensive body of knowledge on the electrochemistry of the electrode-electrolyte interface. More recently, data on the fields around active nerve or muscle fibres have been published, [2]. However, an adequate theoretical treatment of the field problem when a relatively large metallic electrode is introduced among normal and damaged fibres, with the normal fibres depolarizing in a pattern which is more or less random in time and space, seems improbable. As an alternative, some experimental work has been undertaken.

With human subjects it is possible to study signals from voluntary contraction of single motor units in skeletal muscle. Simultaneous exact delineation of the location of the motor unit (or, for that matter, of the active part of the percutaneous electrode) is not feasible. However, indirect data on electrode selectivity can be obtained from these studies. In general, this shows that any of the fine-wire percutaneous electrodes are sufficiently selective to permit utilization of separate control sites as little as one cm apart. As the average diameter of a motor unit in human skeletal muscle is roughly 0.5 cm, control sites spacings less than one cm would seem impractical. Thus these electrodes are sufficiently selective for this application. It is perhaps surprising to note that percutaneous bare wire electrodes, (6-0 stainless steel monofilament suture), inserted in pairs one cm apart in line with the direction of the fibres, do not show appreciably more crosstalk than bipolar wire electrodes with only 2 mm uninsulated tips.

In order to study larger electrodes, it is necessary to resort to surgery. The technique employed in this Institute is to implant the electrodes, and one or more nerve stimulating electrodes, and to make the initial measurements under direct vision prior to closing the incision. Electrode leads are brought out through the skin in a convenient location; subsequent testing is carried out under general anaesthesia without surgery. Finally, electrode locations are verified and the extent of tissue reaction determined at autopsy.

Initial efforts to achieve reasonable crosstalk performance with implanted electrodes which are attached to bone and lie totally outside the muscle sheath have been unsuccessful. However, relatively large (0.8 mm diameter) wire electrodes inserted into the muscle at a point of normal or artificial attachment to bone, and running parallel to the fibres with a 0.5 mm spacing for a distance of 2 cm or more, do permit use of adjacent muscles without excessive crosstalk. The most serious concern with these electrodes is the possibility of long-term tissue damage due to chronic mechanical irritation.

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