2

SELECTIVE RECORDING

The study of electrical activity of a single muscle fiber became possible with the advent of technology allowing selective recording. Single fiber electromyography, SFEMG, was developed to complement concentric and monopolar EMG and to further our understanding of MU microphysiology in health and disease. This chapter will deal with essential theoretical and practical considerations regarding selective recording.

The resting membrane potential of the muscle fiber is about 80 mV, inside negative. A nerve impulse arriving at the endplate, which lies somewhere near the midpoint of the muscle fiber, releases acetylcholine (ACh), which initiates membrane depolarization. From the endplate region a wave of depolarization is propagated along the muscle fiber towards its ends, and the moving electrical field can be recorded outside the muscle fiber as an AP (AP).

Although in theory the AP amplitude decreases exponentially with increasing recording distance [Gath and Stålberg, 1976; Gath and Stålberg, 1977; Gath and Stålberg, 1978], in practice there are always distortions in amplitude and shape. The electrical field is shunted by the metallic recording surface, and an average value of the isopotential lines crossing the electrode surface is recorded (Fig. 2.1). Due to the smaller radius of the isopotential lines and the higher electrical field gradient close to the muscle fiber, distortion is most pronounced at small recording distances, when the amplitude will be less than estimated for a recording from a theoretical point outside the muscle fiber. Distortion is less marked at longer fiber-electrode distances. This shunting effect is pronounced when, as in the case of the commonly-used concentric needle electrode, the leading-off surface of 150 x 580 μm is large relative to the muscle fiber, which has a diameter of 25 to 100 μm. Thus, while the closest muscle fibers naturally have the highest recorded amplitude, the difference between the amplitude of potentials from near and from distant fibers is less than might be theoretically expected. With a larger recording surface, amplitude decay with distance is less, which makes the recording even less selective (Fig. 2.2).

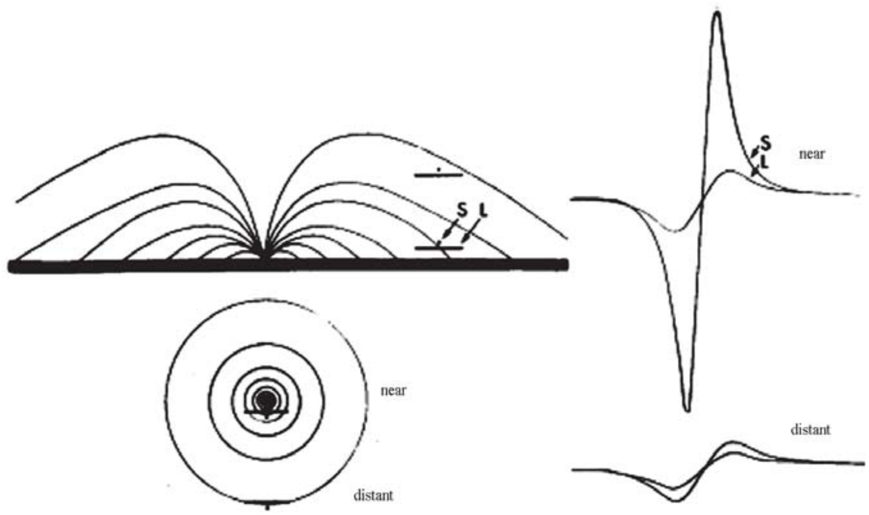

Fig. 2.1. The electrical field around a muscle fiber recorded with a small (S) and a large (L) electrode surface. The large electrode shunts the isopotential lines at short fiber - electrode distances, but less so at longer distances. Thus at a short distance the large electrode records a lower amplitude of the AP than the small electrode.

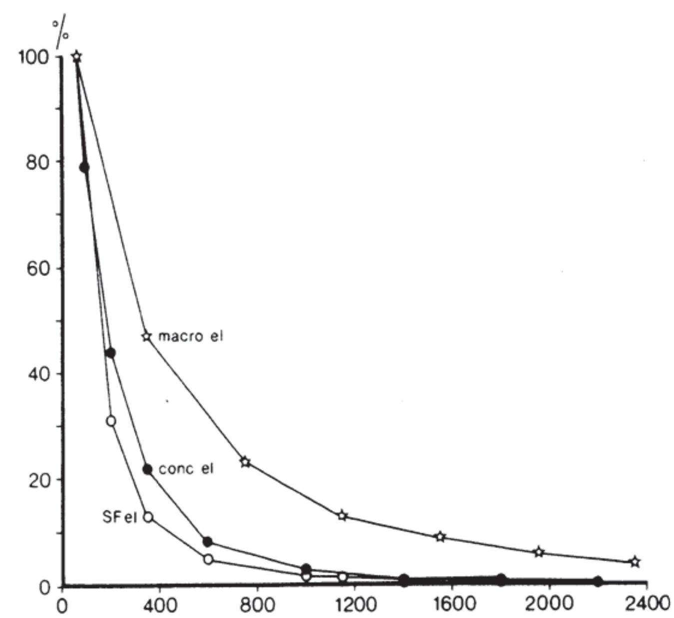

Fig. 2.2. Relative peak-to-peak amplitude of a simulated SFAP at different distances from the fiber surface as measured by a SFEMG (square), concentric needle (round) and Macro (star) EMG electrode. The SFEMG AP was filtered with a 500 Hz high-pass filter. The APs in CNEMG and Macro EMG were not filtered. (Modified from [Stålberg, 1983] with permission.)

2.1 SMALL ELECTRODES

From the foregoing considerations it follows that a more selective recording may be expected from a small electrode, which should increase the amplitude ratio between potentials recorded from adjacent and distant muscle fibers. In practice near muscle fibers give rise to higher APs with the small electrode than with a conventional concentric needle electrode, and APs from distant fibers are of similar size when recorded with SFEMG and conventional EMG electrodes. The selectivity is enhanced by the fact that such a small leading-off surface is likely to be near fewer muscle fibers belonging to one MU than would the case with the concentric needle electrode surface. An electrode diameter of 25 to 30 µm has been shown to be optimally selective [Ekstedt, Häggqvist et al., 1969]. This is smaller than the average normal muscle fiber diameter and causes only minimal shunting of the AP. With further reduction of the recording surface the electrode impedance would increase, which might introduce problems with input amplifier circuits without offering any practical recording advantage. A number of such electrodes have been constructed, some of which are shown in Figs. 2.3 and 2.4.

2.2 NEEDLE ELECTRODES

An electrode with consistent recording characteristics is produced by embedding a 25 µm wire into a cannula, exposing its end at a side port a few millimeters behind the tip (Fig. 2.3A-B) and grinding it flush with the surrounding epoxy resin. Electrodes with one (the most common for routine use) up to 14 such leading-off surfaces have been constructed [Ekstedt, Häggqvist et al., 1969]. The insulation surrounding the wire in the side port produces the so called wall effect, which will increase the recorded amplitude by a factor of up to 2 for adjacent fibers, and less for remote fibers. This type of electrode was used for the studies presented in this book and will be called the SFEMG electrode. Recordings are made from the side-ported wire, using the cannula as reference.

2.2.1 Wire Electrodes

The simplest way to obtain an electrode with a small recording area is to record from the bare tip of a thin insulated wire inserted into the muscle. Wire diameters most commonly used are 50 to 100 µm. The wire is introduced through an injection cannula, which is then withdrawn. An even smaller recording surface can be produced by making a small hole in the insulating coat of a wire by means of a spark. The size of the hole can be on the order of 10 to 20 μm [Hannerz, 1974]. With such small surfaces the shape of single fiber potentials is subject to distortion but selectivity is high, owing to the intrinsic filtering characteristics of the electrode, which acts as a high-pass filter. The size and impedance of this kind of electrode are inevitably very difficult to standardize and quantitative studies such as the analysis of AP shape and the estimation of fiber density are not possible. A special type of electrode is used to record from intact human nerves in microneurography [Hagbarth and Vallbo, 1969]. This is a tungsten wire insulated with lacquer except for the tip, and rigid enough to pierce the skin. It can also be used for muscle recordings, and high selectivity is achieved in combination with a high-pass filter on the amplifier. Such electrodes have not been used for detailed single muscle fiber studies.

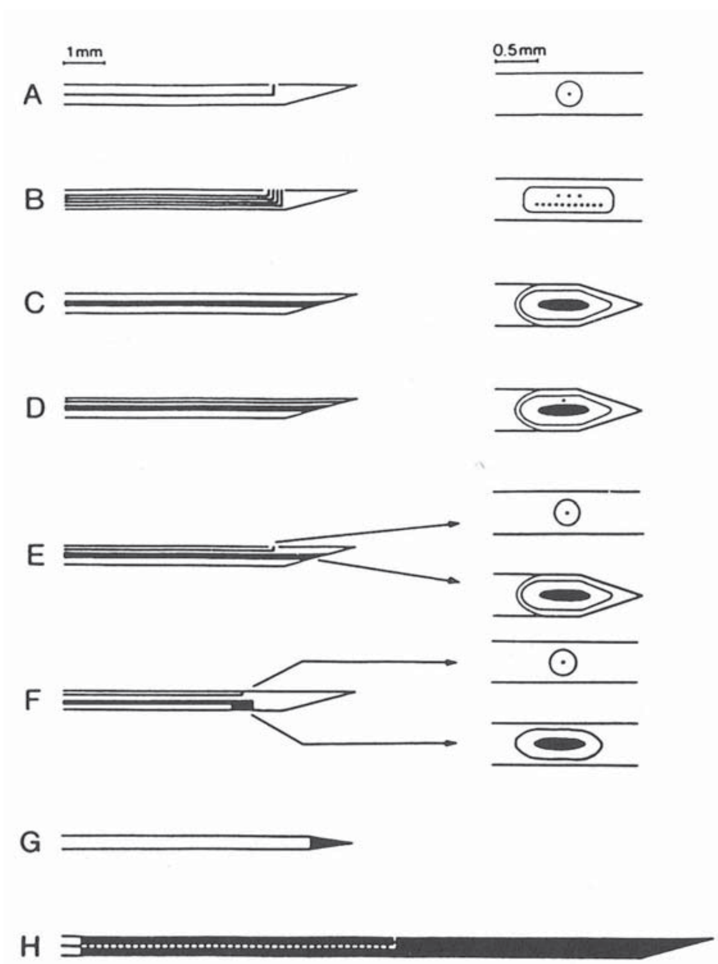

Fig. 2.3. EMG electrodes. A - single fiber EMG electrode with one recording surface. B - single fiber multielectrode. C - concentric needle electrode. D-F - different types of dual electrodes. G - monopolar electrode. H - Macro EMG electrode (From [Stålberg, 1986] with permission.)

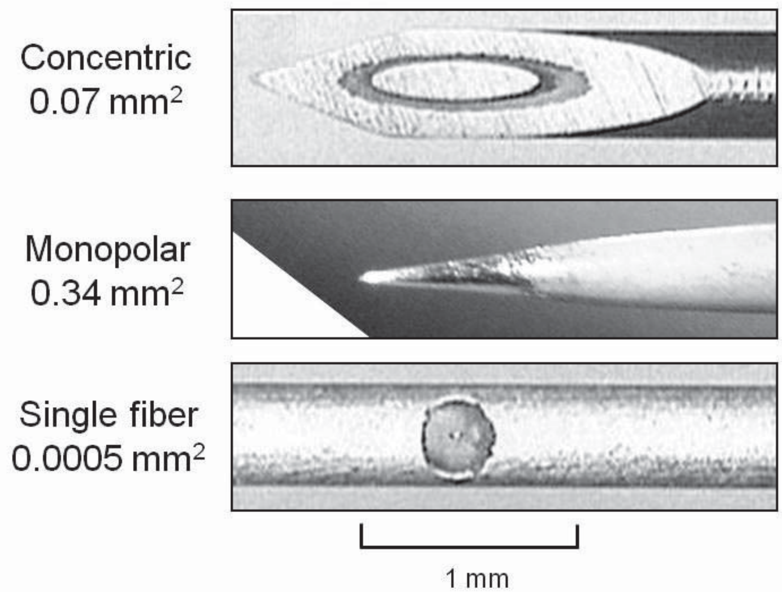

Fig. 2.4. Microphotographs of three types of EMG electrodes. (Figure courtesy S. Nandedkar)

2.2.2 "Bipolar" Recording

The selectivity of EMG recordings can be increased even beyond that obtained with a small recording surface. One way is to use differential recordings between two small electrodes with a short interelectrode distance, i.e., a so-called "bipolar" recording, in which the net signal represents the difference between the signals recorded at each of the two electrodes. APs from fibers equidistant from the two electrodes will be cancelled, while many others picked up by both electrodes will be subtracted and profoundly reduced in amplitude. Thus the uptake area will be restricted and the recording is very selective (Fig. 2.5). The optimal position is with one of the two recording surfaces close to the studied muscle fiber, and with the other (the reference) surface at a right angle to the fiber. The interelectrode distance should not exceed 200 µm - if it is too small the recorded APs will decrease significantly. If the interelectrode distance is too large, the electrodes will be picking up from two independent sources and no common activity will be cancelled. In this situation, APs picked up with the reference electrode will appear with reversed polarity and can thus be identified, but the selectivity of the recording will not be enhanced.

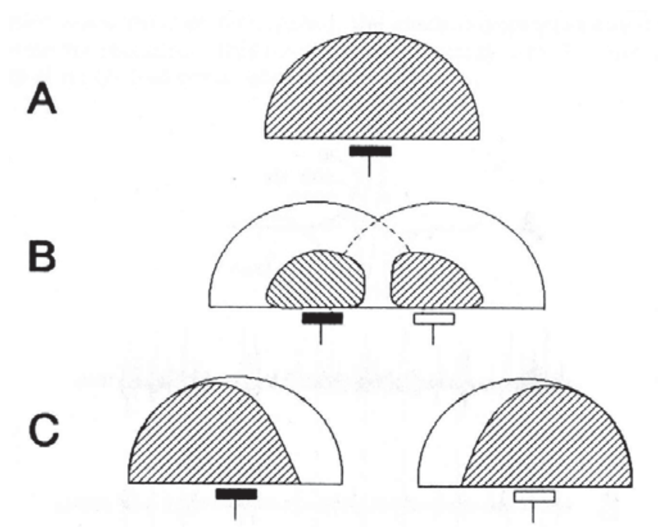

Fig. 2.5. Recording territory with different reference electrodes. A - "Monopolar" recording with a reference electrode outside the muscle. The hatched semi-circle delineates the recording area within which the AP is recorded with 5% (at the border) to 100% of its amplitude (close to the electrode). B - "Bipolar" recording with inter-electrode distance of 100 um. The recording area is markedly reduced compared to A. The APs recorded with the reference surface within the reversely hatched area appear with reversed polarity. C - "Bipolar recording" with inter-electrode distance of 600 µm. Both electrodes record muscle activity and only very little activity is common and cancelled. The effect of this derivation is increased recording territory.

When the AP is volume-conducted through the muscle tissue the different frequency components of the signal are attenuated to different degrees. The tissue is similar to a low-pass filter in that the AP loses its high frequency components relatively faster than its low frequency components. In other words, the APs recorded from distant muscle fibers contain a larger proportion of low frequency components than those from adjacent muscle fibers. This phenomenon can be exploited to reduce the interference from distant muscle fibers and thus increase the selectivity of the recording. By reducing the low frequency response of the amplifier, the amplitude of distant fiber APs is attenuated more than that of an adjacent muscle fiber. With the high-pass filter at 100 Hz (roll off = 12 dB per octave) only slight improvement is obtained, except for the reduction of slow movement artefacts, but at 500 Hz background activity is significantly reduced. The amplitude of APs from fibers close to the electrode is reduced by less than 10%, whereas distant fiber APs are reduced more substantially. At more extreme filter settings of 1000 to 5000 Hz the recorded APs become progressively reduced to the first derivative of the original signal. The amplitude then reflects the rise-time of the original AP [Gath and Stålberg, 1975] (Fig. 2.6).

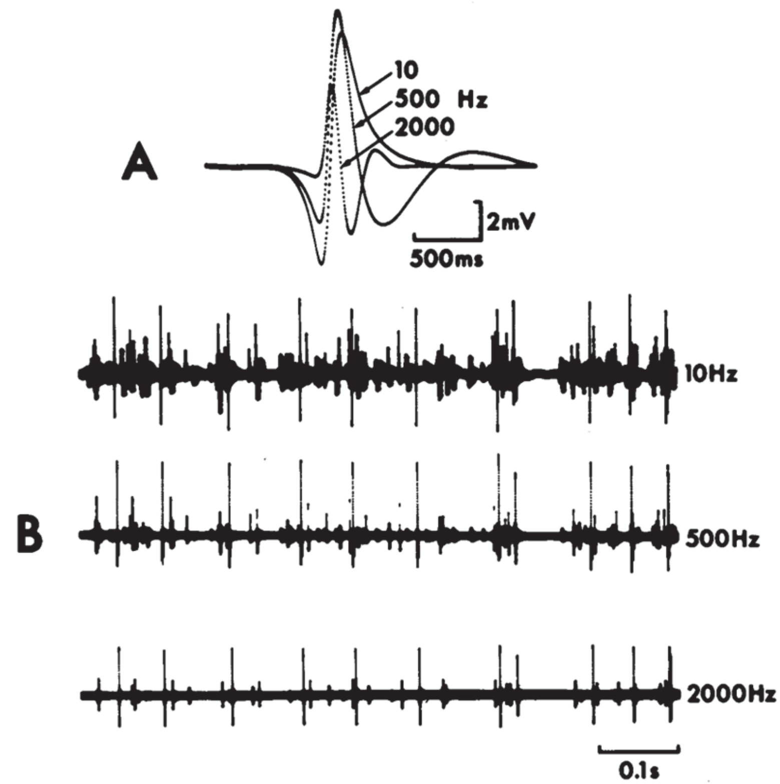

Fig. 2.6. Effect of filtering. A - on the shape and amplitude of the single fiber action potential. B - on the background activity.

By combining a small electrode, a bipolar derivation and high-pass filtering a single fiber potential can sometimes be recorded relatively undisturbed by other active muscle fibers at up to 50 to 75% of maximal voluntary contraction. Similar conclusions concerning selective recording have been presented by Andreassen and Rosenfalck [Andreassen and Rosenfalck, 1977], among others. With increasing selectivity the recording position becomes more critical.

More selective recordings can also be obtained by using high-pass filtering of signals recorded with conventional concentric or monopolar EMG electrodes. This has been used to study both the MUP form and stability ("jiggle") [Payan, 1978; Clarke and Eisen, 1985] and to study the neuromuscular jitter with concentric needle EMG (CNEMG) electrodes (see Chapter 17).