Late Sodium Current in the Node of Ranvier*

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Summary. Voltage clamp experiments carried out on nodes of Ranvier of myelinated fibres of Rana esculenta showed that a small fraction of sodium channels fail to inactivate. Thus during long lasting depolarizing pulses there is a small Na-current superimposed on the leakage and potassium currents. This late Na-current appears more marked in sensory fibres than in motor ones.

Key words: Sodium Permeability — Delayed Currents — Node of Ranvier.

Although a tail of inward current occurring at the end of long lasting depolarizing pulses ("Ip current") was assumed to be carried by Na-ions (Frankenhaeuser, 1962—1963) and should therefore result from a late Na-permeability change, a late Na-current has not been detected in the nodal membrane. The aim of the present communication is to show that a late Na-current may be revealed, particularly in sensory fibres of the frog Rana esculenta. The voltage clamp method used for this work has been described elsewhere (Nonner, 1969).

Analysis of the Membrane Currents for Long Lasting Depolarizing Pulses. Voltage clamp pulses lasting 160—300 msec were applied to the test node superfused with a Ringer solution containing TEA (7.5 mM/l). The corresponding membrane currents were recorded at high gain and measured at the end of pulses. The steady-state current values were then plotted versus membrane potential as shown in Fig. 1. It may be seen that the current-voltage curve (curve A) is slightly N-shaped revealing a late inward current superimposed on the leakage current. This inward component (curve C) is more marked (relative to the leakage current) in sensory fibres exhibiting a conspicuous tendency to repetitive activity. In motor fibres, this component C is smaller or sometimes absent. The current records depicted in Fig. 1a (see inset) show that the steady-state current for a 50 mV depolarizing pulse increases slightly when TTX (3 \cdot 10^{-7} g/ml) is added to the TEA-Ringer solution. Accordingly, the current-voltage curve in TEA + TTX

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Fig. 1. Steady-state $I_{Na}-E$ curves 140 msec after the beginning of the voltage clamp pulses. Ordinate: membrane currents; abscissa: absolute membrane potential. Curve A: Ringer + TEA. Curve B: Ringer + TEA + TTX. Curve C: difference between curves A and B; this curve represents the late Na-current as a function of membrane potential ($E$). The normal resting potential corresponds to $E = -70\text{mV}$. Curves were drawn by eye. Membrane current records (inset): effect of TTX and of Tris-Cl in place of NaCl. The membrane was depolarized 50 mV from its resting level during 160 msec, first in Ringer + TEA (lower traces in both pictures), then, either in TEA-Ringer + TTX (upper trace, record a) or in Tris-Ringer (upper trace, record b). Records obtained on two different sensory fibres (curve B, Fig.1) becomes linear. However, the current measured in TTX exceeds the extrapolated values of the leakage current revealing a small residual rectification probably due to an incomplete blocking of K-channels by TEA. In other words, TTX abolishes a discrete current presumably carried by Na-ions and superimposed on both leakage and residual potassium currents. This interpretation is supported by the following observations: (i) the reversal potential of the TTX-sensitive fraction (curve C, Fig.1) of the total steady current is close to the reversal potential of the early Na-current; for seven axons these reversal potentials were found to be $+47.5 \pm 3.6\text{mV}$ and $+48.5 \pm 3.1\text{mV}$ respectively (average $\pm$ S.d.). (ii) When Tris-Cl is used in place of NaCl in the Ringer solution (see inset, records b, Fig.1) the steady-state current voltage curve is similar to the curve obtained when the test-node is superfused with Ringer solution made with NaCl and containing TEA + TTX.