THE SODIUM PUMP OF MAMMALIAN NERVE CELLS

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Interest in active transport processes of mammalian nerve cells stems from their high rate of oxygen consumption (HOLMES 1930; HELLER and ELLIOT 1955; KOREY and ORCHEN 1959), the high vulnerability to oxygen lack (van HARREVELD 1946; BROOKS and ECCLES 1947; LLOYD 1953; GELFAN and TARLOV 1955; KOLMODIN and SKOGLUND 1959) and high activity of sodium- and potassium-stimulated adenosine-triphosphatase (BONTING, SIMON and HAWKINS 1961; BONTING, CARAVAGGIO and HAWKINS 1962). These data suggest a very rapid active transfer of ions across the nerve cell membrane which maintains the intracellular ionic concentrations.

The first demonstration of active cation transport in motoneurones was made by COOMBS, ECCLES and FATT (1955 a). They injected sodium, tetramethylammonium or choline ions into cat motoneurones by passing depolarizing currents through intracellular microelectrodes which were filled with solutions of salts of the appropriate cation species. Changes thereby induced in motoneuronal potentials indicated that in the intracellular fluid there was a transient increase of the selected cations which accompanied a decrease of potassium and an increase of chloride. There would also be movement of water, balancing the osmolarity between the inside and the outside of the cell. After a sodium injection these changes were gradually restored to the initial levels within ten minutes, while injections of tetramethylammonium or choline ions were followed by only a slow and partial recovery. The fast rate of recovery from the sodium injection was ascribed to the action of the sodium pump, because the recovery was so specific to the sodium injection, and because the presumed sodium efflux after the injection was in opposition to the electrochemical gradient for this ion species.

Recently sodium injections have been repeated, and the results compared with those of other alkaline cations (ARAKI, ITO, KOSTYUK, OSCARSSON and OSHIMA 1962, 1965; ECCLES, ECCLES and ITO 1964 a, b; ITO and OSHIMA 1964 a, b, c). The ionic events occurring after the sodium injection were satisfactorily analysed particularly in those motoneurones which maintained a high resting potential around —80 mV. The resting potential at such a high level was much less sensitive to the intracellular ionic changes produced by the sodium injection than at a relatively low level, and therefore the complication due to an altered resting potential could be eliminated from the measurements of motoneuronal potentials during the recovery phase of sodium injection (ITO and OSHIMA 1964 a, b). It was then possible to calculate the rate constant of the recovery process which characterized active sodium extrusion from motoneurones.
Fig. 1 illustrates the changes produced by a sodium injection in three types of motoneuronal potentials: spike, after-potential and inhibitory postsynaptic potential (IPSP). Immediately after the injection (the second row of Fig. 1)

there was a reduction of the spike amplitude (A) with concomitant decreases of the rates of rise and fall of the spike (B), conversion into depolarization of the after-hyperpolarization that followed the spike (C), and an increase of the IPSP in the depolarizing direction (D). The resting potential was depolarized a little