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Brain Research Reviews 49 (2005) 377 – 387

BRAIN RESEARCH REVIEWS

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Review

Changes during the postnatal development in physiological and anatomical characteristics of rat motoneurons studied in vitro

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Accepted 8 February 2005
Available online 24 March 2005

Abstract

The postnatal maturation of rat brainstem (oculomotor and hypoglossal nuclei) and spinal motoneurons, based on data collected from in vitro studies, is reviewed here. Membrane input resistance diminishes with age, but to a greater extent for hypoglossal than for oculomotor motoneurons. The time constant of the membrane diminishes with age in a similar fashion for both oculomotor and hypoglossal motoneurons. The current required to reach threshold (rheobase) decreases in oculomotor motoneurons, in contrast with the increase observed in hypoglossal motoneurons. The depolarization voltage required to generate an action potential also diminishes in oculomotor motoneurons, whereas it remains constant in hypoglossal motoneurons. A membrane potential rectification (sag) appears in response to negative current steps, hyperpolarizing brainstem motoneurons more than 20 mV relative to the rest. This membrane response is more frequent in adult motoneurons. The durations of the action potential and its medium afterhyperpolarization (mAHP) decrease with postnatal development in all motoneurons studied, although the shortening of mAHP is more evident in oculomotor motoneurons. A rise in firing rate for all motoneurons with age is universal; this trend is also more pronounced in oculomotor motoneurons. Developing motoneurons exhibit a postinhibitory rebound depolarization that is capable of triggering an action potential or a short burst of spikes. This phenomenon is voltage-dependent and requires less of a membrane hyperpolarization to elicit an action potential in adult than in neonatal cells. In all developing brainstem and spinal motoneurons, the adult somal size is reached within the newborn period, although their dendrites continue to elongate. In summary, input resistance, time constant, and durations of action potential and mAHP decrease, while the frequency of sag and postinhibitory rebound, as well as the motoneuron firing rate and dendritic length, increase with postnatal age. These trends are universal to all the motoneuronal populations studied; however, the extent of these changes differs for each motoneuronal pool. A further distinction is evident in the inconsistent age-dependent change in rheobase and depolarization voltage for the two brainstem motoneuron nuclei.

Theme: Development and regeneration
Topic: Motor system

Keywords: Oculomotor motoneuron; Postnatal development; Slice preparation; Rat

Contents

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doi:10.1016/j.brainresrev.2005.02.003

1. Introduction

Information available from in vitro studies about the changes during postnatal development in morphology and electrophysiological properties associated with a particular cell is scarce [4,7,49]. Most of these studies have been conducted using hypoglossal motoneurons [4,7,10,36, 39,68,69], and they have reported substantial changes in both physiological properties and anatomical features with age. For spinal motoneurons, the sequential development of physiological properties studied in vitro has not been accompanied by examination of motoneuron morphology; furthermore, the physiological data are available only for limited epochs [14,18,19,22,32], largely excluding the adult [44].

The above-mentioned physiological variations are characterized by the disappearance, induction, and redistribution of channels in the membrane [10,22,39,52]. Anatomical changes are associated with the elongation and branching of the dendritic trees [36,38]. In parallel with these changes, there are modifications occurring in the properties of targeted muscle fibers and in the synaptic inputs converging on motoneurons of a specific functional phenotype [49,58,72]. Recent research on combined morphology and function of motoneurons has been carried out using in vitro preparations, where the ionic environment can be controlled and pharmacological agents can be easily washed in and out [4,7,22,52].

The neural circuit controlling eye movements is well known [6,55,59], and the morphology and physiological properties of the associated motoneurons have been extensively characterized in both chronic and acute studies [12,13,15,17,21,61,63]. Current in vitro data on these cells are primarily focused on early postnatal development [52,64] and are scarce in the adult [23]. A better understanding of the developmental sequence of events in oculomotor development is needed for two reasons: first, studies will provide insights into how the final physiological and anatomical features in the adult animal are achieved, and second, these studies can reveal whether there is a common sequence for the maturation of mammalian motoneurons. To this end, we have reviewed our recent in vitro findings obtained from antidromically identified motoneurons within the oculomotor nucleus of the rat during the first month after birth and have compared them with data reported in other spinal [18] and brainstem pools [36–38]. The physiological data illustrated in the figures come from 126 oculomotor, 128 genioglossal, and 78 spinal motoneurons. The genioglossal motoneurons are a hypoglossal subpopulation whose physiological properties are representative of the whole nucleus [36–38,68,69]. The anatomical data described here derive from 22 oculomotor and 40 genioglossal motoneurons intracellularly labeled in vitro with neurobiotin.

2. Changes in motoneuron physiological properties with postnatal development

2.1. Subthreshold responses

Subthreshold responses are changes in membrane potential to current pulses that fail to generate an action potential. In oculomotor motoneurons, the magnitude of membrane hyperpolarizations in response to incrementing negative current steps varies with postnatal age (Fig. 1A). In fact, the input resistance, calculated from the plot of current versus voltage, decreases about 25% in this population of motoneurons during postnatal development. In genioglossal and spinal motoneurons [18,37,50], the magnitude of the developmental reduction in input resistance is larger (50% or more) than that found for oculomotor neurons (Fig. 1B). Irrespective of age, brainstem motoneurons have a higher mean input resistance than that of their spinal counterparts (Fig. 1B). Results obtained from in vitro preparations show similar differences in mean input resistance to those measured in acute in vivo preparations for both brainstem and spinal motoneurons [9,15]. The decrement in input resistance with postnatal development could be due, in large part, to an increase in leak-potassium channels [10] and/or proliferation of tonic synaptic inputs [39].

As in young hypoglossal motoneurons [37,68], in newborn oculomotor motoneurons, the voltage response to current negative pulses is nearly linear and exponentially approaches a steady-state level. In contrast, adult oculomotor-like hypoglossal motoneurons exhibit a membrane potential rectification in response to negative current steps [35,37,68]. This rectification is characterized by a depolarizing drift or “sag” that shifts the membrane potential toward the rest and is observable when the cells are hyperpolarized more than 20 mV relative to the rest (Fig. 1C). The amplitude of sag is voltage dependent, being more pronounced with larger negative current steps. This physiological phenomenon has also been reported in spinal