Letters

Accommodation in motoneuron models with passive dendrite: Response to linearly rising currents

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A B S T R A C T

The biophysical properties of cat motoneuron (MN) models with passive dendrite and different sizes have been extensively tested. However, the behavior of these models in relation to accommodation has not been tested yet. The experimental data reported have shown that MNs accommodate to a very limited degree, exhibiting, in some extension, breakdown of accommodation phenomenon. One possible explanation for the latter behavior would be the presence of persistent sodium conductance. The accommodation can be evaluated by observing threshold latency (TL) curve and the accommodation coefficient \( (I/I_0)_s \), obtained from the response to linearly rising currents. The simulation results have showed that the models exhibit breakdown of accommodation phenomenon and much similar accommodation coefficients, despite their type: 1.463, 1.456 and 1.418 to S, FR and FF MN models, respectively. According to these data, all the MN models can be classified as slowly accommodating. Our data suggests that accommodation coefficients cannot be associated to the size or to the type of the MN, and persistent sodium conductance might not be necessary to explain breakdown of accommodation phenomenon in MN soma at all.

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1. Introduction

Biophysically realistic, rather complex, motoneuron (MN) models have been developed to mimic experimentally found motoneuronal characteristics, to enable the study of a wide range of phenomena at the neuronal level. In order to develop biophysically realistic mathematical models, mammalian MN models with passive dendrite and different sizes have been constructed with experimental data from cat lumbosacral MNs only. The biophysical properties of these models have been extensively tested, by dynamic and static tests, where the injected currents vary or not in the time, in order to validate them with a wider set of tests [8]. However, the behavior of these models in relation to accommodation has not been tested yet.

The accommodation has been observed in cat MNs and myelinated nervous fibers, where it depends primarily on changes on the conductances of potassium and sodium [4–6], or possibly on the presence of persistent sodium conductance [3]. The accommodation can be evaluated observing threshold latency curve (TL curve) and the accommodation coefficient \( (I/I_0)_s \), obtained from the response of lumbosacral MNs of cats to linearly rising currents (ramp currents).

The TL curve represents the relation between the instant at which the first action potential occurs (latency) and the current intensity at this instant (threshold current), when a ramp current is injected in the MN soma [2,5].

The TL curve can also be represented by the ratio of the current intensity that has caused the first action potential to the rheobase current of corresponding MN \( (I/I_0) \) in relation to the latency \( (I/I_0)_s \) (normalized TL curve). This representation reduces the scale of the vertical axis to values from 1 to 4 in any MN [5].

The accommodation coefficient \( (I/I_0)_s \) represents the ratio of threshold current at a fixed time of 1 s after initiation of the ramp (the final current of a 1 s ramp with a rate of rise just sufficient to produce an action potential) to the rheobase current [4–6].

This coefficient, within a numerical range, allows classifying the MN as rapidly or slowly accommodating. Values lay between 1.1 and 3.3 in cat MNs, with values between 1.1 and 1.6 being most common. MNs showing \( (I/I_0)_s < 1.6 \) have been classified as slowly accommodating, and the ones who have showed \( (I/I_0)_s > 2.5 \) have been classified as rapidly accommodating [4–6].

The simulations could give some additional clues about the behavior of MNs models of different sizes, besides classifying them as slowly or rapidly accommodating.

2. Methodology of the simulation experiments

The detailed description of the models can be found elsewhere [8]. Briefly, to construct the models, experimental results from type S MN 35/4, type FR MN 43/5, and type FF MN 41/2 described...
in [9,10] have been used for the corresponding models. The models have different values for specific membrane resistivity in order to give them appropriated values of input resistance and rheobase [8]. Six different types of ionic conductances have been included in the soma and two different types in the initial segment. The transient sodium and potassium conductances have been described in a similar form in the models, differing from each other only in the maximal conductance value, which is related to the size of the soma. However, the models do not have persistent sodium conductance.

Following the experimental protocol described in [2,4–6], ramp currents with different slopes have been injected in the soma of the models. Despite the models exhibit different minimum firing rate, the range of the ramp current slope has laid between 35 pA/ms and 5.0 nA/ms for the three models.

In order to register the first action potential, the first instant of time at which the derivative of the membrane potential was 10 mV/ms or higher was taken. The time gap between the beginning of the injection of the ramp current and the instant at which the first action potential occurs, as described above, was the latency of the model. The simulation time was 700 ms, similar to the reported experimental protocol [2,4–6].

In order to calculate accommodation coefficient, a simulated protocol similar to the experimental one reported in [4–6] has been used. The injected ramp current would have to cause only one action potential at 1 s. However, it is computationally difficult to establish this current so that the action potential accurately occurs at 1 s. Therefore, we have established this ramp current (i) adopting a tolerance of ±1% s for the instant at which the only one action potential occurred.

In the simulations, performed by a desktop computer, with a 2.4 GHz processor, 512 MB of RAM memory, and fixed time step of 0.01 ms, the membrane potential of the soma (in mV), the time (in ms) and the injected current (in mA) have been stored in output archives. Then, the TL curves and I/I0 versus latency curves were plotted and the accommodation coefficients were calculated.

3. Results from simulations experiments

Table 1 presents rheobase (I0) values for the three MN models [8].

Fig. 1 presents the TL curves of the MN models. The breakdown of accommodation phenomenon is evident: despite of ramp current slope, the model fires at the same threshold current, except for FF MN model, which exhibits some accommodation. However, in the three models, the value of threshold current at higher ramp current slope is larger than at lower ramp current slope, indicating slow accommodation. The phenomenon is more similar to the ones reported in [1,8], related to transient response to the injection of a ramp current in the soma.

When the threshold currents are normalized by rheobase current, the behavior of the three models is similar. This can be observed on Fig. 2, which presents the ratio of the threshold current to the rheobase current (I/I0) as a function of the latency (normalized TL curve).

Finally, the calculated accommodation coefficients are presented in Table 2.

4. Discussion

The injection of ramp currents has caused repetitive firing response in the models. This response and the TL curves are similar to those reported in literature [2,4–6].

The TL curves in Fig. 1 are similar to those found in [2]. The difference among the curves of the three models has laid in the latency and the amplitude of current. As it has been expected, the threshold current needed to produce an action potential was higher in the model FF, a little lower in FR and even lower in S.
which is coherent to the characteristics of these MNs related to recruitment principle and input resistance. However, in the three models, the value of threshold current at higher ramp current slope is higher than the ones at lower ramp current slope, indicating slow accommodation, as reported in [2].

Differences in the latency cannot be associated to the size of the MN because, in the normalized TL curves (Fig. 2), S and FR MN models have showed practically the same latencies, while FF MN model has showed lower latencies than the two other models.

Moreover, all the models have shown similar accommodation coefficients within a physiological range, being classified as slowly accommodating MNs, characterized by accommodation coefficients \((I/I_0) < 1.6\).”

5. Conclusion

The results are useful as one additional validation test for the mammalian MN models proposed in [8].

All models have shown slowaccommodation with accommodation coefficients within a physiological range, exhibiting the most common values reported to lumbosacral cat MNs, which is coherent to experimental data found in [2], where it has been indicated that MNs accommodate to a very limited degree.

However, a wider range of values has been reported in [4–6], without relating them to the MN type or size, despite of the wide range of values found to rheobase current. Therefore, it is not clear whether or not this wide range of values of accommodation coefficients is related to the type or to the size of the MN. Our results do not support this hypothesis.

Besides, the models exhibit the breakdown of accommodation phenomenon, as reported in [3]. However, our data suggest that, at least at soma, the persistent sodium conductance is neither sufficient nor absolutely necessary to explain this phenomenon because our models do not have this type of conductance [8].

The behavior of the transient sodium and potassium conductances is supposed to be involved in accommodation and breakdown of accommodation phenomena [4]. Our results suggest that the proper modeling of these conductances is sufficient to reproduce the peculiarities of these properties in cat lumbar MN, indicating a careful effort in modeling, as the classical works in MN modeling [77] from which the analyzed models have derived [8].

References


