Morphometric and Functional Correlation of Human Neuronal Somata: Pyramidal Motor, Special Sensory and General Sensory Systems

By

Masakazu SHIBATA¹, Noboru GOTO²,³, Jun GOTO²,⁴, Naoko NONAKA⁵ and Masanori NAKAMURA⁵

¹Kanagawa University of Human Sciences, Faculty of Health and Social Work
²Department of Anatomy, Showa University School of Medicine, ³Koriyama Institute of Health Sciences
⁴Department of Medicine, Tokyo Metropolitan Matsuzawa Hospital
⁵Department of Oral Anatomy and Developmental Biology, Showa University School of Dentistry

– Received for Publication, October 27, 2008 –

Key Words: Cell size, Image analyzer, Morphology, Neuron, Staining method

Summary: Using an ideal tissue preparation method, we found a definite correlation between various human neuronal somata from the view point of accurate morphometry and functional evaluations. We believe this study may be of value, or even indispensable in the correct understanding of neurological symptomatology and phenomenology.

Although there are huge numbers of nerve cells in the human central and peripheral nervous systems, morphometric comparison of neuronal somata related to their functions is rather rare, except for our own studies¹–³ where we used an ideal preparation method that yields the lowest recorded shrinkage ratio and the narrowest shrinkage range⁴.

Classic explanations regarding the size and morphology of neurons have been made by Ramon y Cajal (1899) in his textbook⁵. He concluded as follows: “Physiologic characteristics do not appear to be related to size either. Although, in general, motoneurons are huge, some are very small; and sensory cells in dorsal root ganglia, as well as many retinal ganglion cells, are also large.” His explanations have been accepted all over the world. However, since there were no modern morphometric techniques in his time, and his research was performed mainly with the silver impregnation method which may cause a wide range of strong tissue shrinkage, any comparison, in the strict sense of the word of neuronal sizes, under the microscope, in different parts of the nervous system or in different individuals using this method may not yield totally accurate results.

With the help of a new preparation method and modern morphometry, we have conducted a comparative study of representative human neuronal somata for the reconsideration of those results from the morphological and functional points of view.

Methods

Over the past twenty years, we have prepared many tissue sections of the human brain, spinal cord and spinal ganglia using the modified Klüver-Barrera (K-B) staining method after secondary chromic acid fixation followed by nitrocellulose embedding⁶. For the study of various nuclei such as the oculomotor, trochlear, inferior collicular, motor trigeminal, principal sensory trigeminal, abducens, facial, vestibular, ambiguus, hypoglossal, cochlear, medial superior olivary, solitary tract, trigeminal spinal tract, von Monakow, Goll, Burdach, we selected several sections of the cerebral cortex containing the precentral and postcentral gyri and of the diencephalon containing the posterior ventromedialis and ventrolateralis (VPM and VPL) thalamic nuclei from a 60-year-old male, as well as serial sections of the brainstem and cerebellum from a 63-year-old female. For the selection of the anterior horn cells and posterior horn proprius cells, the spinal cord of another 60-year-old male was cut into the cervical, thoracic, lumbar and sacral segments. Transverse sections in each segment were prepared. Serial
sections of the C5 spinal ganglion in the same male were also made.

Details of the staining methods and morphometry have been given in our previous reports1–4.

### Results

We examined neuronal somata in the human nervous system as follows: (1) the pyramidal motor system (Betz cells, anterior horn cells at the levels of C5, Th8, L2 and S2; nerve cells of the motor cranial nuclei in the brain stem such as oculomotor, trochlear, motor trigeminal, ab-

<table>
<thead>
<tr>
<th>Size group</th>
<th>Representative neuron</th>
<th>Pyramidal motor</th>
<th>Special sensory</th>
<th>General sensory</th>
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</thead>
<tbody>
<tr>
<td>Very large (15,000 µm²)</td>
<td>SG (large size cells)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Large (9,000–15,000 µm²)</td>
<td>SAH, LAH, Facial nerve, Betz, Motor trigeminal</td>
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<td>Medium (5,000–9,000 µm²)</td>
<td>Oculomotor, Ambiguus, Hypoglossal, CAH</td>
<td>Lateral vestibular, Inferior vestibular</td>
<td>SG (medium size cells)</td>
<td></td>
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<td>Small (2,000–5,000 µm²)</td>
<td>Trochlear, Abducens, TAH</td>
<td>Lateral geniculate (layer 1–6), Medial geniculate, Medial superior olivary, Dorsal &amp; ventral cochlear, Superior &amp; medial vestibular, Solitary tract</td>
<td>VPM, VPL, Principal sensory, Zonal trigeminal, Magnocellular trig, von Monakow</td>
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<tr>
<td>Very small (&lt; 2,000 µm²)</td>
<td>Inferior collicular</td>
<td>Cortex Area 3 (layer 4–6), Goll &amp; Burdach, Trig sp tr, gelatinous, CPH, TPH, LPH, SPH</td>
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Abbreviations: CAH: Cervical anterior horn cell; CPH: Cervical posterior horn proprius cell; G: Neuron of Goll nucleus; LPH: Lumbar posterior horn proprius cell; SAH: Sacral anterior horn cell; SG: Spinal ganglion cell; SPH: Sacral posterior horn proprius cell; TAH: Thoracic anterior horn cell; TPH: Thoracic posterior horn proprius cell; Trig sp tr: Trigeminal spinal tract nucleus; VCN: Ventral cochlear neuron; VPL: Ventralis posterolateralis; VPM: Ventralis posteromedialis
ducens, facial, ambiguus and hypoglossal nuclei); (2) the special sensory neurons in the medial and lateral geniculate bodies, ventral and dorsal cochlear nuclei, medial superior olivary nucleus, solitary tract nucleus, vestibular nuclei (superior, medial, lateral and inferior); and (3) the general sensory neurons in the spinal ganglia, cortical Area 3 of Brodmann (layers 4–6), thalamic nuclei (VPM and VPL), posterior funicular nuclei (of Goll and Burdach), sensorius principalis nucleus of the trigeminal nerve, subnucleus zonalis, gelatinosus and magnocellularis in the caudal part of the trigeminal spinal tract nucleus, proprius posterior horn nuclei (cervical, thoracic, lumbar and sacral) of the spinal cord.

Apart from morphological differences of neuronal somata, the morphometric data are summarised in relation to their functions in the Table. The very large neuronal somata (over 15,000 µm$^2$ in area) were found only in the spinal ganglion. The neuronal somata of the pyramidal motor system ranged from the large neuron group (9,000–15,000 µm$^2$ in area) to the small neuron group (2,000–5,000 µm$^2$ in area). Those of the special sensory system belonged mainly in the small neuron group (2,000–5,000 µm$^2$ in area) with some exceptions in the medium (5,000–9,000 µm$^2$ in area) and very small (less than 2,000 µm$^2$ in area) neuron groups (see the Table). Those of the general sensory system ranged mainly from the small (2,000–5,000 µm$^2$ in area) and to the very small (less than 2,000 µm$^2$ in area) neuron groups with an exception in the medium neuron group (see the Table).

**Discussion**

The conventional K-B preparation method without secondary chromic fixation causes strong shrinkage of tissue, including a wide range of shrinkage ratios (30–70% in length) after paraffin embedding. However, the preparation method we employed only gives a practical shrinkage ratio of 10 ± 0% in length. It is therefore perfectly suitable for morphometric studies of the nervous system. As for the conventional hematoxylin-eosin stain and silver impregnation methods, they also cause a wide range of strong tissue shrinkage regardless of embedding methods.

As the size of neuronal somata is usually related to the thickness of axons, we can consider that it may be concerned with the conduction velocity of neuronal processes.

We can conclude that the pyramidal motor system contains neuronal somata of large or medium size, the general sensory system contains neuronal somata of small or very small size, and the special sensory system contains neuronal somata of intermediate sizes between the other two systems, —although this classification of neuronal somata does not give a clear-cut explanation (see the Table), the only exception being in the case of the very large (huge) size (over 15,000 µm$^2$ in area) of neuronal somata in the spinal ganglion. This may be due to the spinal ganglion being the part of the reflex arch that conducts pain sensation and is therefore necessary for a quick response.

**References**