ČASOPIS LÉKAŘŮ ČESKÝCH, 144, 2005, No. 10

REVIEW ARTICLE

Purkinje's Concept of the Neuron

Pokorný J., Trojan S.
Charles University, Medical School I, Institute of Physiology, Prague, Czech Republic

SUMMARY

With his experiments and findings, Jan Evangelista Purkinje (spelled Purkyně in Czech) left his trace in 34 scientific disciplines; in some, he is even considered to be their founder (embryophysiology, histology, pharmacological physiology, biophysics, comparative physiology). He was a pioneer in the field of neuroscience not only because of his neuroanatomical descriptions, but to an even greater extent because of his neurophysiological experiments. Besides providing a description of "Purkinje's cells" and cells of other regions of the brain, Purkinje investigated the structure of neuronal processes and can be credited with the first description of dendrites. Available historical records show that Purkinje also performed research into the structure of the hippocampus. Those and other papers indicate that Purkinje recognized possible functional differences between various types of neurons and speculated about their interrelations. Only now, with our current detailed insight into the structure of hippocampal neuronal circuits, our understanding of mediator interaction and modulation, together with the identification of neuroplastic processes in the hippocampus, are we able to complete Purkinje's attempt to correlate structure with function.

Key words: J. E. Purkinje (J. E. Purkyně), nerve fibre, hippocampus; principal neuron, interneuron.

Čas. Lék. čes., 2005, 144, pp. 659-661.

With his experiments and findings, Jan Evangelista Purkinje (spelled Purkyně in Czech) left his trace in 34 scientific disciplines; in some, he is even considered to be their founder (embryophysiology, histology, pharmacological physiology, biophysics, comparative physiology). He was a pioneer in the field of neuroscience not only because of his neuroanatomical descriptions, but to an even greater extent because of his neurophysiological experiments. He consistently performed these experiments, particularly in the years from 1832 to 1837 in Wroclaw, Poland. Initially, Purkinje made macroscopic studies of nerves and tissue of the central nervous system (1824). For more detailed study, Purkinje used powerful magnifying glasses and the microscopes available at that time. In 1832 Wroclaw University purchased Plössl's achromatic compound microscope; later, in 1841, Purkinje's assistant Oschtz, together with the institute's mechanic, built (at the initiative of Purkinje) the first slide microtome. This made it possible to focus research into nervous tissue to more subtle details. Besides the description of "Purkinje's cells" and cells of other regions of the brain, Purkinje investigated the structure of neuronal processes and can be credited with the first description of dendrites. Available historical records show Purkinje also carried out research into the structure of the hippocampus. Those and other papers indicate that Purkinje recognized possible functional differences between various types of neurons and speculated about their interrelations. Only now, with our current detailed insight into the structure of hippocampal neuronal circuits, our understanding of mediator interaction and modulation, together with the identification of neuroplastic processes in the hippocampus, are we able to complete Purkinje's attempt to correlate structure with function.

According to Valentin, a disciple of Purkinje's, Purkinje demonstrated the structure of nerve fibres to students as early as 1829, when he used the method of fibre bundle loosening in a hypertonic potassium solution. In 1836 Valentin presented this observation along with his own research data, already referring to "bodies discovered by Purkinje" (Körperchen entdeckt von Purkinje) (1). Purkinje himself described these cellular formations in April 1837 (Schlesische Gesellshaft für die vaterländische Kultur), showing them (the illustrations are still preserved) during his lecture at Karolinum (Charles University, Prague) at a congress of German natural scientists and physicians held in September 1837. Judging by an abridged record of the lecture and the illustrations, Purkinje identified cells in the substantia nigra, locus coeruleus, thalamus, corpora geniculata, cornum Ammonis, cerebellar cortex, in the oliva inferior and in the pons Varoli.

In his lecture given at Karolinum in 1837 Purkinje also described neuronal projections: "In fresh nerves, placed alongside and squeezed, expelled from their sheaths, there were similar transparent central lines, which I later realized were solid parts and called them nerve axial cylinders (Nervencylinder, Axiscylinder). In his paper dated 1838 Purkinje commented on the content of the nerve fibre referring to it as a "protein substance" (2). Theoretical conclusions drawn from this observation confirmed the assumption that nerve fibres could not be hollow tubes transferring "spiritus animales", as imagined by classical writers. Their task might have been the transfer of energy, "vis nervosa" (3).

Purkinje himself again subscribed to his discoveries in Živa (4), a Czech journal of natural sciences, in 1858, saying "… my main thoughts about the relevance of primary components of the nervous system, particularly where I first speculated about an analogy between egg embryos and ganglial bodies. As regards their role, I commented that I had initially considered them to be central organic formations, whereas their concentric composition around the central

---

Address for correspondence:
Prof. Jaroslav Pokorný, MD. D.Sc.
Charles University, Medical School I, Institute of Physiology
128 00 Prague 2, Albertov 5
Czech Republic
E-mail: jaroslav.pokorny@lf1.cuni.cz

nucleus, their relation to elemental nervous fibres seems to be the centre of power points, giving rise to power lines, efferent and afferent as with ganglia and ganglial nerves, as the brain to the spine and brain nerves, whereby nervous activity would originate, distract and concentrate."

Theoretical conclusions from his study of nerve fibres suggested Purkinje's permanent effort at seeking a correlation between morphology and function. This continued in an attempt at classifying nerve fibres by their diameter. Quantitative measurements were made possible by the then new and exact ocular micrometer, permitting measurements with an accuracy of up to 1/500 mm. Purkinje with his co-workers demonstrated a difference between the thickness of fibres of posterior, sensory roots (smaller diameter) and anterior motor roots (larger diameter) (4-6). These observations confirmed Bells theory of reflective action and reflective arch (7). A comparative study of several animal species showed that differences in the thickness of sensory and motor fibres can be generalized. Measurements confirming these findings were not undertaken before the 1930s (8).

Purkinje is also to be credited with the first description of neuronal dendrites. While the description first appeared in a paper by Valentin (1), he mentioned the neuronal dendrites in connection with Purkinjes cerebellar cells (Körperchen entdeckt von Purkinje). Valentin coined the term "Monada" as a reference to an association between the neuronal body and processes (previously, neurons and nerve fibres were considered separate entities).

Purkinjes efforts at correlating morphology and function resulted in his theory on neuronal function.

In Purkinjes concept, ganglial bodies (somata) play a central role and act as energy generators (Kraftzentra). In this concept, nerve fibres act an energy conductor (Kraftlaitungslinien), with some fibres distributing energy whilst others serve as energy collectors. Hence, neurons are relatively separate functional centres connected by their processes and fibres. Neuronal function is determined by their position within the nervous system hierarchy. This suggestion of neuronal theory may have contributed to a full description of neurons (9) and, later, the formulation of the neuronal doctrine (10).

Records of Purkinjes lectures presented at Karolinum (1837) suggest that he was also involved in the study of the structure of the hippocampus. These and other works indicate that Purkinje was aware of potential functional differences between the neurons. It was not until later that findings allowed these differences to be formulated: for example, Ramón y Cajal (10, 11) described the intricate structure of neuronal processes and suggested the complexity of possible interactions. Likewise, papers by Lorente de Nó, another author of the "classic era" of neuromorphology (12) gave rise to the notions of principal neurons and interneurons. Whereas principal neurons have a relatively uniform structure and involvement, the shape of the body, dendritic and atonal branching of interneurons, just as their involvement in neuronal circuits, are fairly variable. Considerations regarding interneuronal function include notion of inhibition along with a description of excitatory (Gray type I) and inhibitory synapses (Gray type II) (13, 14). A breakthrough came with evidence of the ultrastructure of endings of basket cells on the bodies of hippocampal pyramidal cells suggestive of type II synapses (15). Another step was evidence that basket cell endings survive even in chronically isolated brain cortex islets (16). The inhibitory nature of some interneuronal synapses was further supported by evidence of the presence of glutamate decarboxylase, an enzyme synthesizing gamma-aminobutyric acid, the main inhibitory neurotransmitter in the brain (17).

However, similar neuroanatomical, histochemical and, later, immunochemical analysis of hippocampal interneurons challenged the basic classification of neurons. While the category of principal neurons including pyramidal cells remained, evidence of reverse collaterals of their axons, ending as typical interneuronal axons (18), as well as the identification of interneurons projecting to the more remote parts of the brain (19) questioned this division. As a result, it is perhaps only the "GABAergic non-principal neurons" in the hippocampus, which are consistent with the classical classification into the category of interneurons (20).

At present, the extremely detailed insights into the structure of neuronal circuits of the hippocampus, mediator interaction and modulation as well as evidence of the activity of neuroplastic processes in the hippocampus make it possible to complete Purkinje's attempt to correlate structure and function. The hippocampus plays the pivotal role in the formation of memory traces of declarative memory. Through changes in their activity, CA3 neurons respond both to audiogenic and visual, tactile, and olfactory stimuli. Multiple challenges quickly result in habituation without reducing response to other stimuli. The implication is that CA3 neurons do not respond to the qualitative aspects of the stimulus but to its "newness". In the CA1 region, neurons respond mostly to a single sensory modality and to comprehensive properties of the stimulus. Some CA1 region pyramidal cells respond to specific spatial features. For example, in experiment, they increase their activity when the experimental animal is transferred to a specific area of the study space. The cells responding in this manner are referred to as "place cells" (21).

Processing of sensory information in the hippocampus may be followed by entering the information into the memory. Spatial information seems to be entered in the form of changes in the efficacy of synapses specifically distributed across the entire neuronal population. Neurons active to a specific stimulus are functionally interconnected, so that each further activation of several members of this subpopulation results in the recruitment of other neurons of the group. "Mossy cells" could be an important component of such organized groups, as they converge with entry from granular cells and they themselves form excitatory ipsilateral and contralateral synapses with granular cells in the vast region of the hippocampus. These mossy cells thus link specific selected granular cells, which, while they may be fairly distant one from the other, are activated simultaneously. In this concept, information would be placed on synapses between mossy cells and granular cells (22).

The internal arrangement of hippocampal formation and the relation to surrounding structures also projects specifically on to its potential involvement in some pathological processes, as evidenced by a host of clinical and experimental observations. Temporal epilepsy, the most challenging pharmacologically treatable form of epilepsy, seems to develop primarily in the hippocampus (23). This increased susceptibility to epileptiform activity is due to a combination of cellular factors with neuronal circuit characteristics.

However, the tendency of the hippocampus to epileptiform activity is generally closely associated with normal function of the region of the brain. Excitatory interactions comprise part of facilitation mechanisms and are related to neuroplastic processes determining the processes of learning and memory. In addition to plasticity at the levels of synaptic transfer, the hippocampus shows considerable capacity for plasticity at the level of interneuronal synapses. The ability of neoformation of afferent synapses (24) is directly associated with neoformation of axonal collaterals in the epileptic brain (25, 26). Additionally, neuronal neoformation has been demonstrated in the hippocampus, which is likely to be also associated with neuronal circuit plasticity (27). The arrangement of the hippocampus is thus a compromise of sorts between properties of cells and neuronal circuits allowing the highest degree of plasticity yet still capable of preventing development of pathological features.

With his brilliant interpretation of his own morphological discoveries, Purkinje laid the basis for functional morphology in neurosciences. The scope of Purkinje's activities in neurosciences was impressive indeed: subjective observations in the area of sight (1818 – 1825 – 1840), methods of examination of the eye (1823), acoustic studies (1808–1822), audio perception (1824–1862), physiology of human speech (1827–1865), physiology of dizziness and postural mechanisms (1820–1827), studies of skin senses (1853), physiology of sleep and waking state (1846–1849), conditional reaction (1818–1830), and experimental injury to individual parts of the CNS (1824). A climax of Purkinje's investigations in the field of neurosciences was his concept of the function of the nervous system as a whole, which Purkinje formulated in 1847 - heralding neuron theory.

Still, Purkinje may have seen beyond the knowledge available then, as suggested by his observation: "Each organic, living part (cell, grain, fibre) has a dual existence, one external, material, whereby it resides physically and chemically in its dwelling and presents itself to senses; the other, internal, embryonic, life-giving, fetal, whereby it develops, under natures laws, into adulthood, propagation and, eventually, death." This idea can be interpreted as Purkinje foreseeing genetic mechanisms governing the formation and structure of cells (tissue), potential to modulate them (plasticity of their expression) by environmental factors and, perhaps, the above potential of regeneration of some elements of neuronal circuits.

This work was supported by grant: MSM 0021620816.

REFERENCES

1. **Valentin, G.:** Über den Verlauf und die letzten Eden der Nerven. Verh. Kais. Leopold.-carol. Akad. Natur., 1836, 10, p. 50-240 (cited according to Gutmann E.: Purkyně's concepts on nerves and some aspects of current neurobiology, pp. 183-187, published in. J. E. Purkyně Centenary symposium, University of Jan Evangelista Purkyně, Brno, 1971)
2. **Purkyně, J. E.:** Neueste Untersuchungen aus der Nerven- und Firnanatomie. Bericht ü. d. Versammlung deutscher Naturforscher und Ärzte, Prag, Sept. 1837. Prag, Haase, 1838, pp. 177-180.
3. **Procháska, G.:** De functionibus systematis nervosi. Commentatio. Wolfgang Gerle, Pratur, 1784.
4. **Purkyně J. E.:** Podrobné zprávy o mojích starších i novějších literárních, zvláště přírodnických pracích. Praha, Živa, 1858, pp. 36-45, 103-109, 183-189, 242, 246.
5. **Remak, R.:** Weitere mikroskopische Beobachtungen über die Primitivfasern des Nervensystems der Wirbeltiere. Froriep´s neue Notizen aus dem Gebiete der Natur- und Heilkunde, 1837, pp. 36-41.
6. **Rosenthal, D.:** De numero atque censura microscopica fibrillarum elementariam systematis Cerebro-spinalis symbolae, In: J. E. Purkyně Opera Omnia, VI, ed. Kruta, V. and Hornof, Z., Praha, 1954.
7. **Bell, Ch.:** On the Reflex Functions of the Medulla Oblongata and the Medulla Spinalis, Royal Society, London 1811. In: An Exposition of the Natural System of the Nerves of the Human Body, Republication of the Papers delivered to the Royal Society, 1824.
8. **Eccless, J. C., Sherington, C. S.:** Proc. Roy. Soc. 106B, 1930, p. 326.
9. **Deiters, O.:** Untersuchungen über Gehirn und Rückenmark des Menschen und der Säugethiere. (Braunschweig), 1865.
10. **Ramón y Cajal, S.:** Estructura del asta de Ammon y fascia dentata. Ann. Soc. Esp. Hist. Nat., 22, 1893.
11. **Ramón y Cajal, S.:** Histologie de systeme nerveux de l'Homme et des vertebres tomme II. Paris, Maloine, 1911.
12. **Lorente de Nó, R.:** Studies on the structure of the cerebral cortex – II. Continuation of the study of the ammonic system. J. Psychol. Neurol., 1934, 46, pp. 113-177.
13. **Gray, E. G.:** Axo-somatic and axo-dendritic synapses of the cerebral cortex: an electron microscope study. J. Anat., 1959, 93, pp. 420-433.
14. **Andersen, P., Eccles, J. C., Loyning, Y.:** Recurrent inhibition in the hippocampus with identification of the inhibitory cell and its synapse. Nature, 1963, 198, pp. 540-542.
15. **Colonnier, M.:** Synaptic patterns of different cell types in the different lamina of the cat visual cortex. An electron microscope study. Brain Res., 1968, 9, pp. 268-287.
16. **Szentágothai, J.:** The synapse of short local neurons in the cerebral cortex. In: Modern trends in neuromorphology (Szentágothai, J., ed.), Budapest: Akademiai Kiado, 1965, pp. 251-276.
17. **Ribak, C. E, Vaughn, J. E. Saito, K.:** Immunocytochemical localization of glutamic acid decarboxilase in neuronal somata following colchicine inhibition of axonal transport. Brain Res., 1978, 140, pp. 315-332.
18. **Pokorný, J., Schwartzkroin, P. A.:** Do hippocampal CA3 pyramidal cells project into the dentate hilus? Poster at the 21st Annual Meeting of the Society for Neuroscience, New Orleans, November 11-15, 1991. From the proceedings of the Society for Neuroscience, Vol. 17, p. 126.
19. **Seress, L., Ribak, C. E.:** GABAergic cells in the dentate gyrus appear to be local circuit and projection neurons. Exp. Brain. Res., 1983, 50, pp. 173-182.
20. **Freund, T. F., Buzáki, G.:** Interneurons of the hippocampus. Hippocampus, 1996, 6, pp. 343-470.
21. **O'Keefe, J.:** Spatial memory within and without the hippocampal system. In: Seifert, W. (ed.), Neurobiology of the Hippocampus. Academic Press, New York, 1983, pp. 375-403.
22. **Buckmaster, P. S.; Schwartzkroin, P. A.:** Interneurons and inhibition in the dentate gyrus of the rat in vivo. J. Neurosci., 1995, 15, pp. 774-789.
23. **Spencer, S. S.; So, N. K.; Engel, J. Jr., Williamson, P. D.; Levesque, M. F.; Spencer, D. D.:** In: Surgical treatment of epilepsies. Ed.: Engel, J. Jr. Raven Press, New York, 1993, pp. 359-377.
24. **Cotman, C. W.; Nadler, J. W.:** Reactive synaptogenesis in the hippocampus. In: Neuronal Plasticity. Ed. Cotman, C. W., Raven Press, New York, 1978, pp. 227-271.
25. **Sutula, T., Cascino, J., Cavazos, J., Parada, I., Ramirez, L.:** Mossy fiber synaptic reorganization in the epileptic human temporal lobe. Ann. Neurol., 1989, 26, pp. 321-330.
26. **Franck, J. A., Pokorný, J., Kunkel, D. D., Schwartzkroin, P. A.:** Physiologic and morphologic characteristics of granule cell circuitry in human epileptic hippocampus. Epilepsia, 1995, 36(6), pp. 543-558.
27. **Hong-jun Song, Stevens, Ch. F., Gage, F. H.:** Neural stem cells from hippocampus develop Essentials properties of functional CNS neurons. Nature Neuroscience, 2002, 5, pp. 438-445.

Translation: René Prahl

COMMENTARY

Comments on the Paper by Pokorný and Trojan: "Purkinje's Concept of the Neuron"

The authors should be commended for addressing a topic that was so thoroughly investigated by Jan E. Purkinje, earning him a fine international repute for research. One cannot but admire the amount of work Purkinje was able to carry out while using the technology and techniques then available. Current research profits greatly from his work, as evidenced by texts showing how advanced technology has furnished better insights into the structure and function of the nervous system. His main finding was that there is no function without a corroborative structure. Purkinje's observations of various "fiber thickness" of the posterior spinal nerves and anterior motor nerves anticipate the modern findings as reported by Eccles and Sherington by more than 70 years. It is commendable of the authors to indicate that Purkinje as perhaps the first scientist to describe the dendrites. There is a further question: who was the first to assign Purkinje's name to the major cerebellar cortical cells – was it Ramón y Cajal or Purkinje's disciple Valentin? Valentin was the author who coined the term monada, referring to an association between the neuronal body and processes. The issue of the hippocampus and its structure has been crucial in the research into the entire limbic system; and all this was achieved decades before the discovery of chemical synapses, interneurons, and the whole neuronal network, which can also be currently investigated *in vivo* in man. The more we know about specific function of various areas of the brain, the more we realize the importance of their interrelations, and that the neuronal network seems to contain some nodal structures referred to shortly as "centers", e. g., symbolic function centers, sensory cortical terminals. Further evidence of the links is presented by the integration of memory traces of individual senses, generalization of an epileptic seizure, etc.

In conclusion, the authors of the paper indicate effectively Purkinje's concepts regarding neuronal plasticity and genetics.

Translation: René Prahl

Address for correspondence:
Prof. Jiří Tichý, MD., D.Sc.
Department of Neurology, 1st Faculty of Medicine, Charles University
128 21 Prague 2, Kateřinská 30
Czech Republic
E-mail: jiri.tichy@lf1.cuni.cz